Card Sorting Test Performance: The Role of Visual Working Memory and the Effect of Visual Feedback

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Submitted in fulfilment of the requirements for the Degree of
Doctor of Philosophy (Clinical Psychology)

School of Psychology
University of Tasmania
November, 2006

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Acknowledgements

I would like to express my thanks to friends and colleagues whose support and encouragement have made this thesis possible. Mostly, I would like to thank my supervisor, Dr Clive Skilbeck, for his invaluable advice, guidance, encouragement, and accessibility. The brainstorming sessions we had during the conceptual stages of the project never failed to stimulate and motivate me. Throughout my candidature you provided me with many opportunities to develop my knowledge and understanding of neuropsychology for which I am eternally grateful. I could not have asked for a better supervisor and mentor.

Thank you also to Tracey Dean whose assistance with the final stages of data collection was very much appreciated. To Diana Murdoch, thank you for your unfailing friendship and support over these many years and for your thoughtful review of the final draft. Finally, special thanks go to my family for their patience, advice, love, and understanding.

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Abstract

Poor performance on the Wisconsin Card Sorting Test (WCST: Heaton, Chelune, Talley, Kay, & Curtis, 1993), a test of executive function, has been attributed to deficits in information processing, cognitive flexibility, inhibitory control, and working memory. Previous WCST studies, involving student participants, have indicated a primary role for the phonological loop and/or central executive components of working memory, whereas studies involving individuals with schizophrenia or schizotypic traits have indicated spatial working memory involvement. So far, no study has investigated the role of the visual and spatial subcomponents of the visuospatial sketchpad or has included all components of working memory within the one study. The visual aspects of the WCST have also been overlooked in many studies, although Cinan and Tanör's (2002) findings suggested that the presence or absence of visual feedback from previous response cards might differentially affect performance.

Therefore, the aim of this thesis was to clarify the role of working memory in performance of the WCST, using Baddeley and Hitch's (1974) working memory model as a conceptual framework. The series of experiments examined the contribution to WCST performance by the phonological loop, the central executive, and the visual and spatial subcomponents of the visuospatial sketchpad. It also investigated the effect of visual feedback on the individual working memory components. Participants included university undergraduates psychometrically identified as having schizotypal personality traits (schizotypy) and mild to moderate head-injured patients.

Experiments 1A and 1B explored the relationship between schizotypy, working memory, and card sorting test performance using computerised versions of the WCST and the Madrid Card Sorting Test (MCST: Barceló & Knight, 2002). No significant differences were found between high and low schizotypic scorers on any dependent measure. However, low scorers on working memory tasks performed significantly worse than high scorers on all card sorting test variables. Additionally, performance was differentially affected by the presence (WCST) or absence (MCST) of visual feedback.

After piloting the appropriate secondary tasks in Experiment 2, a dual-task paradigm was used with a nonclinical population in Experiment 3. Results indicated significant involvement of the visual subcomponent when visual feedback is absent and greater involvement of the phonological loop when visual feedback is present. Experiment 4 further explored this dissociation in a group of head-injured patients with differential impairments in executive functioning, auditory working memory, and visual working memory. The results showed card sorting test performance was significantly worse for patients with visual working memory impairment than for any other group.

Overall, the results from this thesis suggest that the visual subcomponent of the visuospatial sketchpad, which has previously been overlooked, contributes significantly to card sorting test performance; and that the degree of contribution of the individual components maybe differentially affected by the presence or absence of visual feedback. These findings have implications for both the methodology used in future experimental studies and for the interpretation of WCST performance in clinical practice. A redesign of the WCST procedure is proposed to enable the clinician to differentiate between poor performance due to perseveration and that due to distractibility.

CHAPTER 1

Overview of the Thesis

Interest in frontal lobe functioning began when, on 13th September 1848, an accidental explosion at a railroad construction site in Cavendish, Vermont resulted in a tamping iron, 3 cm thick and 109 cm long, penetrating the face, skull, and brain of Phineas Gage before exiting through the top of the skull (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; Mesulam, 2002). Gage regained full consciousness almost immediately after the accident and was able to converse with astonished co-workers. Subsequent to an infection, he appeared to make a full recovery with no impairment of movement, speech, memory, or intelligence. However, there was an extreme change in personality. Prior to the injury he had been considered a responsible, capable, efficient, and socially well-adapted individual whereas post injury he became irresponsible, irreverent, unpredictable, and irrational and was never again able to live a fully independent life. Twenty years after the accident and five years after Gage's death his former physician, John Harlow, made the observation that the changes in Gage's behaviour and cognitive processes correlated with focal damage to the frontal lobe. Recently, Damasio et al. (1994) investigated the possible location of Gage's lesion with the use of modern neuroanatomical analysis techniques. They concluded that although Gage's injury probably involved the ventromedial regions of both frontal lobes while sparing the dorsolateral regions, the frontal neurons of any region might involve the cognitive processes of attention, working memory, and categorisation. Subsequent to the Gage case, the frontal lobes have been associated with a complexity of higher cognitive abilities that have been collectively termed *executive functions*. Throughout the twentieth century to the present day the enigma of the frontal lobes and executive functions has been investigated from a neuroanatomical and neuropsychological perspective, with the addition of functional neuroimaging techniques in the latter half of the century.

Our understanding of the structural organization of the prefrontal cortex has been advanced by concurrent ablation studies in monkeys, functional studies in humans, and by the development of comparative cytoarchitectonic maps of the two species (Petrides & Pandya, 1994). Additional studies using comparable tests of cognition for non-human primates and humans, such as the self-ordered pointing task (Petrides & Milner, 1982) and the Wisconsin Card Sorting Test (Roberts, Robbins, & Everett, 1988), have also provided invaluable information about the neural bases of memory, visuospatial attention, and a variety of neurodegenerative and neuropsychiatric disorders (Roberts, Robbins, & Weiskranz, 1998). Whilst neuroanatomical studies have clarified the structure of the prefrontal cortex, functional neuroimaging techniques have extended our knowledge of its functional organization. These techniques have also provided an insight into the interactions between different brain regions, as well as the potentially different processing components of the prefrontal cortex (Roberts et al., 1998).

As mentioned previously, *executive functions* is a global term used to describe a complex array of cognitive abilities. As detailed in Chapter 2 executive functions comprise abilities that enable behaviour to be goal-directed and have more recently been found to involve both cortical and subcortical areas of the brain. The majority of tests of executive function are multifactorial involving many, and sometimes different, cognitive processes which may account for the lack of correlation between several executive function tasks (Lehto, 1996). Nevertheless, tests of executive function have been an integral part of neuroanatomical and neuroimaging studies in providing a greater understanding of the relationship between brain structure, neural activity, and goal-directed behaviour. What is less understood are the cognitive processes underlying executive functions and the relationship between these cognitive processes and the clinical presentation of impaired performance on these tests. A better understanding of this relationship would provide the opportunity for the development of more appropriate and specific strategies for rehabilitation and/or may provide more accurate information regarding functional outcome.

The present thesis attempts to clarify the role of one cognitive process, working memory, in performance of what some researchers consider is the gold standard of executive function tests (Royall et al., 2002), that is, the Wisconsin Card Sorting Test (WCST). As described in Chapter 3 the WCST is one of the most extensively used tests of executive function in clinical and experimental neuropsychology. Whilst its multifactorial structure has made it sensitive to executive impairment, its lack of specificity as a marker of frontal lobe functioning has been confirmed by neuroimaging studies that found neural activity in prefrontal and nonfrontal regions of the brain during performance of the test. In previous studies, working memory has been shown to be significantly correlated with the WCST but not with other executive tasks such as the Tower of Hanoi or Goal Search Task (Lehto, 1996). Although there are several theories of executive function and working memory, which are reviewed in Chapter 2, Baddeley's (1986, 2000, 2001) and Logie's (1995, 2003) working memory models, which are described in more detail in Chapter 4, are the most well researched and well supported. These models of executive functioning are used as the basis for the series of experiments described in this thesis.

Previous studies investigating the cognitive underpinnings of WCST performance or the relationship between working memory and the WCST are reviewed in Chapter 5. Although studies have been conducted in normally functioning populations and with patients with frontal lobe lesions, Alzheimer's disease, schizophrenia, and schizotypal personality disorder there is a need for a specific series of studies to link the findings from a nonclinical to a clinical population. Consequently, Chapters 6-9 describe experiments conducted in normal populations with a final experiment, described in Chapter 10, involving patients with mild to moderate closed head injury. In Chapter11 the thesis concludes with a discussion of the overall findings with regard to the working memory models and clinical implications. A redesigned WCST is proposed and directions for future research are suggested.

CHAPTER 2

Executive Functions and the Prefrontal Cortex

Executive functions encompass a range of abilities that enable a person to formulate and achieve a goal; therefore they include abilities such as planning, organization, initiation, self-monitoring, and the ability to maintain all relevant information 'on-line' in order to direct behaviour toward the completion of that goal. Attention, working memory, cognitive flexibility, hypothesis generation, and response inhibition are some of the cognitive processes purported to underlie these executive abilities. However, the investigation of executive functions and their underlying processes has proved difficult.

In the first half of the twentieth century researchers debated on whether the frontal lobes were even associated with executive function due to the inconsistencies in presentation of patients with frontal lobe lesions (Mesulam, 2002). Nevertheless, with advancement in neuropsychological instruments, clinical assessment methods, and an acknowledgement of the neurological basis of emotion and personality, by the second half of the century there was substantial evidence in support of a frontal lobe-executive function connection. Distinctive behavioural syndromes became associated with injury to specific areas within the frontal lobes (Cummings, 1993). Damage to the prefrontal convexity was manifested by impairment in problem-solving, mental flexibility, planning, and judgement; disinhibition and irritability marked orbitofrontal damage, and a medial-frontal injury produced apathy and diminished initiative. Consequently these syndromes were once described as 'frontal lobe syndromes'. However, similar behavioural changes were also observed in patients with lesions to other brain regions. Subsequently, five frontal-subcortical circuits have been described to provide an understanding for these changes, which include disorders of executive function, personality changes, and mood disturbances (Cummings, 1993).

2.1 Neuroanatomy of executive functions

The five circuits are a motor circuit originating in the supplementary motor area, an oculomotor circuit originating in the frontal eye fields, and the dorsolateral prefrontal circuit, lateral orbitofrontal circuit, and anterior cingulate circuit, all three of which originate in the prefrontal cortex and are credited with mediating executive functions.

According to Royall et al., (2002) the role of the prefrontal cortex in executive function is due to its unique structure and pattern of connectivity. The prefrontal cortex is connected to more brain regions than any other cortical region, its position allows for the integration of information that is processed at lower levels, including input from the limbic circuits, and it is the major target of the basal ganglia-thalamocortical circuits. The three frontal circuits relevant to executive functioning share the common structures of the frontal lobe, striatum, globus pallidus, substantia nigra, and the thalamus. Although nonoverlapping, behavioural changes associated with each circuit can be distinct or mixed depending on the location of the lesion. At the cortical level the circuits are widely separated so behaviours associated with one circuit can be distinguished from those of another. Subcortically, however, the circuits are in much closer proximity so a lesion in these regions is more likely to involve multiple circuits (Cummings, 1993; Royall et al., 2002; Royall & Mahurin, 1996).

The *dorsolateral prefrontal circuit* (Figure 2.1.) originates in Brodmann's areas 8-12, 46 and 47. It projects to the dorsolateral caudate nucleus which receives input from the posterior parietal cortex and premotor areas, then connects to the dorsolateral part of the globus pallidus and rostral substantia nigra reticulata, and continues to the parvocellular area of the medial dorsal and ventral anterior portions of the thalamus. Projections from the thalamus back to the dorsolateral prefrontal cortex close the circuit. Higher cognitive functions such as goal selection, planning, sequencing, concept formation, set shifting, working memory, self-monitoring and self-awareness have been found to be impaired with lesions of the dorsolateral prefrontal circuit (Cumming, 1993; Royall et al., 2002).

The *lateral orbitofrontal circuit* (Figure 2.1.) originates in the ventral anterior and inferior lateral regions; Brodmann's areas 10-15 and 47. This circuit projects to the ventromedial caudate nucleus, which receives input from other cortical association areas and brainstem regions, then continues to the dorsomedial portion of the globus pallidus and rostromedial portion of the substantia nigra reticulata, and continues to the magnocellular area of the medial dorsal and ventral anterior portions of the thalamus. The circuit is completed by projections back to the lateral orbitofrontal cortex. Lesions to this circuit have been found to result in marked changes in personality, including disinhibition and impulsivity, and to clinical features such as environmental dependency and utilisation behaviour (Cummings, 1993; Royall et al., 2002).

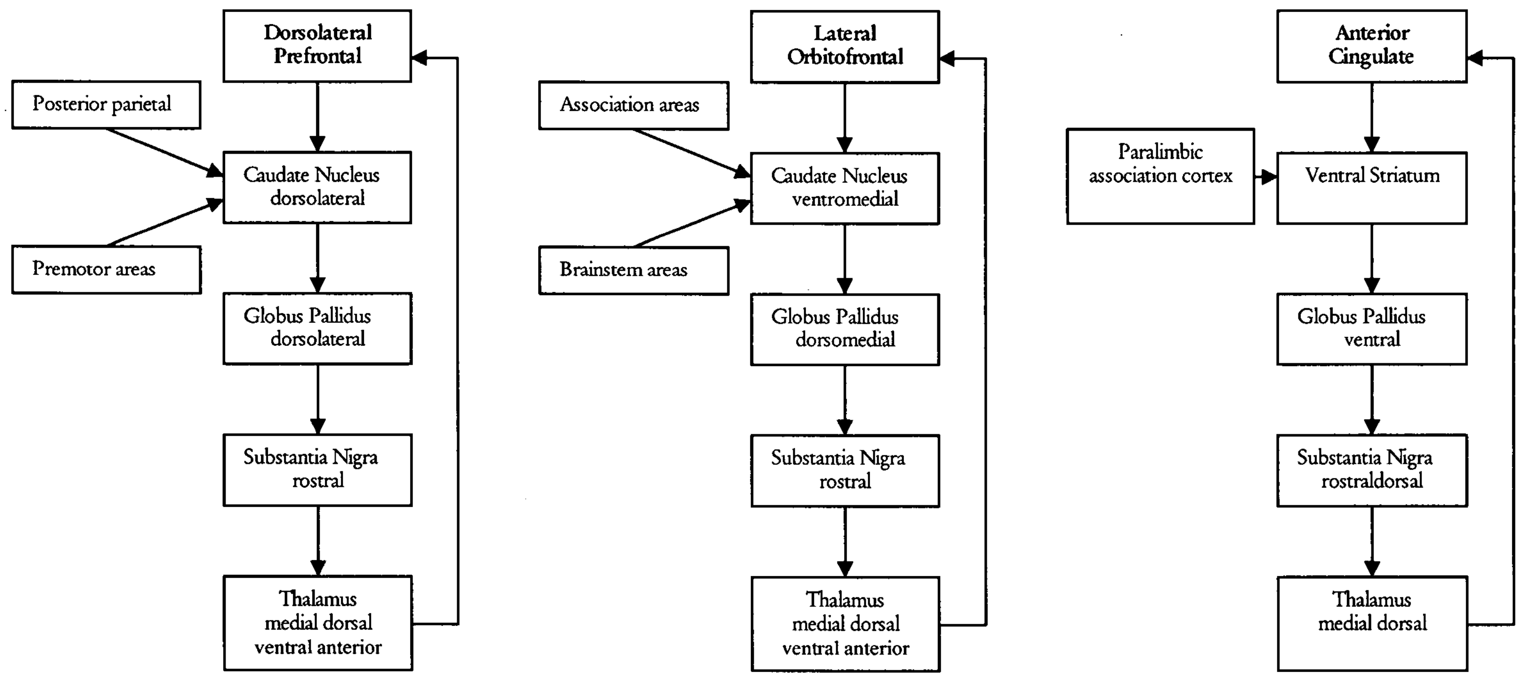

Figure 2.1. The three frontal-subcortical circuits originating in the prefrontal cortex that are relevant to executive functioning.

The *anterior cingulate circuit* (Figure 2.1.) involves medially located areas of the frontal lobe; Brodmann's areas 9-13, 24 and 32. Projections connect to the ventral striatum (nucleus accumbens and olfactory tubercle), which receives input from the paralimbic association cortex, including the anterior temporal pole, amygdala, inferior hippocampus, and entorhinal cortex. It continues to the ventral part of the globus pallidus and rostrodorsal substantia nigra reticulata, then to the medial dorsal thalamic nucleus. The anterior cingulate circuit appears to involve response inhibition and motivational factors, as lesions to this circuit can result in apathy and lack of initiative with the extreme case of akinetic mutism being associated with bilateral lesions (Cummings, 1993; Royall et al., 2002).

The identification of these adjacent yet nonoverlapping circuits has provided an explanation to account for the similarity of behavioural changes related to lesions in different brain regions. Whilst focal lesions to the respective areas of the prefrontal cortex have led to distinct 'frontal lobe syndromes' the involvement of multiple circuits in subcortical lesions and degenerative processes has resulted in syndromes with mixed behavioural manifestations (Cummings, 1993). For example, patients with Huntington's disease, a disorder that mainly affects the caudate nuclei, have exhibited personality alterations (including apathy), mood changes, and obsessive-compulsive behaviours, as well as cognitive abnormalities similar to those manifested by patients with dorsolateral prefrontal lesions. Similarly, studies of lesions to the globus pallidus (Laplane, Baulac, Widlöcher, & Dubois, 1984; Strub, 1989) have described patients with marked changes in personality and reduced activity levels with neuropsychological deficits affecting memory and executive functions, but with normal intelligence and language ability.

Executive dysfunction can, therefore, occur with lesions to any part of the circuits. Direct and indirect effects can also occur due to the finely balanced metabolic interaction between neurotransmitters; an increase in glutamatergic excitation or a reduction in dopaminergic inhibition in subcortical areas can lead to increased cell activity within the prefrontal cortex and a loss of executive control (Royall et al., 2002).

Whilst neuropsychological evaluations were used in the past to determine the approximate location of lesions, the development of neuroimaging techniques such as positron emission tomography (PET), single-photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI) has led to greater sensitivity and specificity in detecting structural brain lesions (Stern & Prohaska, 1996). Nevertheless, the localisation of executive functions has remained problematic, leading to a number of theories about the role of the frontal lobes in executive function.

2.2 Theories of frontal lobe function

The many theories of frontal lobe functioning that have been proposed attempt to address the question as to how relevant information is selected and used to guide behaviour through decision processes towards the completion of a goal. Whereas some theories take a processing approach, some view frontal lobe functioning from a representational perspective, and others view the frontal lobes as a mechanism for memory retrieval.

Norman and Shallice (1986) proposed a two level system to account for the regulation of behaviour. At the lower level is Contention Scheduling, an automatic process in which action-thought schemas are stored and activated by environmental or conceptual thought stimuli. The higher-level system, the Supervisory Attention System, reflects conscious awareness, which focuses attention on and controls the activation level of the schemata so as to bias which schema is selected. This system is only active when the routine schemata do not exist, are not sufficient to achieve a goal, or when the situation requires automatic responses to be overcome (Grafman, 1995; Shallice, 2002; Shallice & Burgess, 1991).

Similarly, Stuss and Benson proposed an automatic-control process theory but with a three-tiered hierarchical structure (Stuss et al., 2002). In their model the lowest level reflects the automatic processing of sensory and basic information that is stored in posterior regions of the brain. The supervisory system provides conscious control of multiple interacting processes and the highest level is involved in abstract thinking, self-monitoring, and metacognition.

Although the dynamic filtering theory (Shimamura, 2000, 2002) involves the executive control of semantic and episodic memory retrieval by different regions of the prefrontal cortex, its basic premise appears to be similar to a supervisory system. It proposes four aspects of executive control (selecting, maintaining, updating, rerouting) that act as filters, which maintain and inhibit activations between the prefrontal cortex and regions in the posterior cortex by way of feedback loops. The level of complexity of each filter varies, with selecting being the least demanding and rerouting the most demanding. When a memory requires retrieval, first it needs to be selected by attention being focussed on perceptual information or memory representations stored in posterior cortices. The memory then needs to be actively maintained so that any updating of the information can occur. Finally rerouting, which could also be considered task switching, occurs if memory activations become irrelevant and a shift from one process or response to another is required.

Duncan and Miller's (2002) automatic-control processing approach is quite different from those described above. In their Adaptive Coding Model they propose a global attention system in which neurons are adaptable to constantly changing information. They suggest that the neurons selectively focus only on relevant information and that this selectivity acts as a control mechanism to direct the contribution of other brain systems.

In contrast to the aforementioned theories that ascribe processes to the prefrontal cortex, Grafman (1995, 2002) proposed a hierarchical cognitive structure in which sets of events are stored as single units in memory, termed a Structured Event Complex governed by the Managerial Knowledge Unit. A Managerial Knowledge Unit is a particular kind of Structured Event Complex that governs cognitive behaviour and is composed of a series of events. Within the prefrontal cortex Managerial Knowledge Units are the most responsible for the storage and expression of executive functions. At the base of the proposed hierarchy are Structured Event Complexes that include the rules, procedures, and skills required for an event. Situated at the top of the hierarchy are abstract Managerial Knowledge Units that represent event series that have a beginning, goals, actions, and an ending; that is, they represent the conceptualisation of goal-directed actions.

Likewise, Fuster (2002) addresses the issue of executive functions from a representational aspect and also suggests a hierarchical structure in which representations increase in generality and abstraction from the bottom up. However, rather than the storage of events in memory as proposed by Grafman, Fuster's model of a perception-action cycle posits that schemas of sequential action are maintained in neuronal networks within the prefrontal cortex and that the representation and execution of sequences of action relies on the temporal integration of information from perception, action, and cognition. Temporal integration is purportedly served by at least four prefrontal functions – attention, working memory, preparatory set, and monitoring.

The term, working memory, is used to refer to a limited capacity system within the prefrontal cortex that contributes to the planning and guiding of behaviour by storing, maintaining, and manipulating information (D'Esposito & Postle, 2002). One of the most extensively investigated theories of working memory is that of Baddeley and Hitch (Baddeley, 2000, 2001), which is discussed in more detail in Chapter 4. Initially they proposed a three component system consisting of two slave systems, the phonological loop and the visuo-spatial sketchpad, which are regarded as storage systems for verbal and visuospatial information respectively, and a central executive component assumed to be an attentional control system capable of integrating and manipulating information from the slave systems and long term memory. More recently Baddeley added a fourth component, the episodic buffer, which is assumed to be a temporary storage component that provides an interface between the slave systems and long-term memory (Baddeley, 2000).

Logie's (1995, 2003) model of working memory is similar to that of Baddeley and Hitch (1974) and is also discussed in more detail in Chapter 4. It comprises two subcomponents for the storage (phonological store) and rehearsal (inner speech) of aurally presented information, two subcomponents for the storage (visual cache) and rehearsal (inner scribe) of visuospatial information and a component labelled 'executive functions' which is analogous to Baddeley's central executive. Unlike the Baddeley and Hitch model, however, Logie proposes that information only gains access to the working memory system via long-term memory and that there is no direct link between working memory and the processes of perception.

An alternative model, which views storage and control functions as intertwined rather than separate entities as in Baddeley's or Logie's model, is that of Braver, Cohen, and Barch (2002). They propose a single mechanism, *context representation*, which might collectively aid working memory, attention, and inhibitory functions. Context representation, they define as "any task-relevant information that is internally represented" (p.430) and can include, for example, goal representations, specific previous stimuli, task instructions, or intended actions. The active on-line maintenance of these representations biases attention and subsequently influences response processing.

Empirical evidence in support of any one of these theories requires the use of measures that bring into play executive functions, such as initiation, judgement, reasoning, and abstraction, irrespective of whether the method used is neuroanatomical, behavioural, or involves neuroimaging techniques.

2.3 Neuropsychological view of executive functions

Whilst neuropsychological tests play an important role in the scientific study of executive functioning, their primary use is in providing information about a patient's functional ability (Stern & Prohaska, 1996). In the clinical setting tests of executive function are part of a neuropsychological evaluation in which memory, mood, attention, language, and motor, perceptual, and visuospatial abilities are also assessed. According to Stern and Prohaska it is the relationship between performance on executive function tests and performance on tests in other domains that provides the most useful information for differential diagnosis. Whilst deficits in executive functioning can be gleaned from behavioural observation, formal tests are often required to identify more subtle deficits particularly in high functioning individuals. Tests also enable the clinician to clarify specific aspects of functioning. For example, whether a person's memory problems are due to difficulties in the encoding, maintenance, or retrieval of information, or whether the problem is more related to impaired attentional processes.

Three tests of executive function relevant to this thesis are the Trail Making Test (Reitan & Wolfson, 1985), the Brixton Spatial Anticipation Test (Burgess & Shallice, 1997), and the Controlled Oral Word Association Test (Benton, 1968). The Trail Making Test is a pencil and paper test that consists of two parts (A & B), which measures cognitive flexibility, divided attention, visual scanning, and visuomotor tracking. Participants are required to connect consecutively numbered circles on form A, and then on form B to connect consecutively numbered and lettered circles alternating between the two sequences. The most common scoring method is the amount of time taken to complete the test, which incorporates the correction of errors made by the participant.

The Brixton Spatial Anticipation Test measures conceptual formation and consists of 56 pages each printed with 10 circles (two rows of five) in which one circle is coloured. The position of the coloured circle on each page is determined by one of nine rules. The participant is told that the coloured circle "moves around according to various patterns that come and go without warning" and that their "job is to pick up on the pattern". They are then asked to state the expected position of the coloured circle on the next page.

The Controlled Oral Word Association Test is a test of verbal fluency and consists of three word-naming trials. The most extensively used set of letters are F-A-S. The participant is required to say as many words as they can think of in one minute beginning with the specified letter, excluding proper nouns, numbers, and the same word with a different suffix.

Some of the other more common tests used to assess executive functions are the Tower of Hanoi and Tower of London tests (Shallice, 1982) (planning & response inhibition); Gorham Proverb Test (Gorham, 1956) and the Category Test (Reitan & Wolfson, 1985) (abstraction & concept formation); Wechsler Comprehension and Similarities subtests (Wechsler, 1997a) (judgement & verbal reasoning); Design Fluency tests (e.g., Ruff, Light, & Evans, 1987) (initiation & fluency); Stroop test (Stroop, 1935), Go/no-go tasks, Hayling Sentence-Completion test (Burgess & Shallice, 1997) (response inhibition & impulse control); and Luria's Motor Programming tasks and Graphomotor sequences (Luria, 1966).

A single test considered to be the most sensitive measure of executive function is the Wisconsin Card Sorting Test (WCST) (Grant & Berg, 1948; Royall et al., 2002; Stern & Prohaska, 1996). This test uses concept formation, sustained attention, verbal and nonverbal working memory, cognitive flexibility, and response inhibition, and has been found to activate widespread frontal regions in neuroimaging studies. Alternative card sorting test versions have also been developed in response to the distress experienced with the original test, particularly by frontal lobe patients (Nelson, 1976) or in an attempt to isolate specific components of problem-solving ability assessed by the WCST (Barceló, 2001; Delis, Squire, Bihrle, & Massman, 1992).

In summary, the term *executive functions* has proved to be a difficult concept to measure, or define, as exemplified by the lack of correlation between executive tasks (Lehto, 1996). Whilst the discovery of three frontal-subcortical circuits thought to mediate executive function has helped clarify the relationship between performance on executive tasks, dysexecutive behaviour, and brain lesion location an understanding of the cognitive processes subserving these functions and the tests that measure them is still the focus of many research studies. The central aim of this thesis is to clarify the role of one cognitive process, working memory, in performance of the executive task, the Wisconsin Card Sorting Test.

CHAPTER 3

Wisconsin Card Sorting Test Performance

The Wisconsin Card Sorting Test (WCST) was originally developed by Grant and Berg (1948) to measure abstract reasoning ability and to ascertain the relationship between response feedback and an individual's ability to shift from one response to another. Milner (1963) subsequently established it as a test of prefrontal lobe functioning following her study, in which patients with dorsolateral frontal lobe lesions achieved significantly fewer categories and more perseverative errors than either patients with orbitofrontal or posterior lesions. Heaton (1981) later published the WCST as a clinical instrument after standardising the test instructions and scoring procedure (Spreen & Strauss, 1991). He also developed a computerised version of the WCST (Heaton, 1990) that has become popular in clinical settings, as it has been shown to yield similar results to the manual version whilst eliminating the onerous task of scoring for the clinician (Artiola i Fortuny & Heaton, 1996).

The WCST (Heaton, 1981; Heaton et al., 1993) consists of four key cards (one red triangle, two green stars, three yellow crosses, four blue circles) and two sets of 64 response cards that depict all possible combinations of colour, number, and form. Participants are instructed to sort the response cards into four groups beneath the key cards and are given verbal feedback as to whether they are correct or incorrect with each sort. The sorting criteria are not revealed nor is the participant told when the predetermined correct category (in the order of colour, form, number, colour, form, number) is changed which occurs after ten consecutive correct responses. The test is considered as completed with the attainment of six categories or when all 128 response cards have been used. Whilst many scores can be derived from the data (trials to first category, numbers of categories achieved, total errors, perseverative errors, perseverative responses, nonperseverative errors, failure to maintain set, learning to learn, % conceptual level responses), the most informative with regard to frontal lobe or executive function are considered to be the number of categories achieved and number of perseverative errors (Heaton et al., 1993; Lezak, Howieson, & Loring, 2004; Nelson, 1976; Spreen & Strauss, 1991). Perseverative errors are defined as an incorrect response to a new category, which would have been a correct response for the immediately preceding category. The index scores are highly interrelated and appear to measure primarily problem-solving/ cognitive flexibility (see Lezak et al., 2004). However, its reliability as a measure of problem solving ability is considered poor for participants who have already solved it once. Although retest scores for nonclinical samples and traumatic brain injured (TBI) patients have reflected improvement, retest correlations even with an alternate form have been found to be .63 or less.

In clinical settings the standard WCST has been criticised for being too lengthy and frustrating to administer, and too distressing for many patients. A high rate of refusal has been reported in some clinical settings, particularly with severely impaired or elderly patients who have had difficulty understanding the test requirements and have become distressed at perceiving the negative feedback as arbitrary (Greve, 2001; Nelson, 1976; Sherer, Nick, Millis, & Novack, 2003; Smith-Seemiller, Franzen, & Bowers, 1997). In response to these criticisms, shortened or alternative versions have been devised.

3.1 Alternative card sorting tests

One logical and practical alternative is the single pack 64-card WCST (Greve, 2001). Comparability between this shortened version and the full 128-WCST has been found in studies with TBI patients (Sherer et al., 2003) and patients with neurological and psychiatric disorders (Vayalakkara, Devaraju-Backaus, Bradley, Simco, & Golden, 2000). Overall, good reliability and validity for the 64-WCST standardised with the 128-WCST normative data has been found (Purdon & Waldie, 2001) but with some exceptions; poor reliability (r=.52) and validity for the total number of correct responses, relatively poor reliability (r=.70) for number of failure to maintain set, and poor validity for the number of categories achieved. When Axelrod (2002) used the standard scores derived from the 64-WCST norms, published by Psychological Assessment Resources (Greve, 2001), he found that once the 64-WCST scores were adjusted for demographic information they were not comparable to the 128-card WCST and thus cautioned clinicians in their use of data from the 64-WCST.

Two other alternative card-sorting tests that have become well used in clinical settings are the California Card Sorting Test (Delis et al., 1992) and Nelson's (1976) modified WCST. Whilst the California Card Sorting Test was designed to isolate and measure specific components of problem-solving ability, specifically concept formation and abstraction (Greve, Farrell, Besson, & Crouch, 1995), the modified WCST was designed to enable more patients to attempt the test and to provide a less ambiguous research tool for discriminating between patient groups.

The California Card Sorting Test (Delis et al., 1992) consists of three sets of six cards with a single word printed on each card. For each set of cards there are three conditions; (1) participants are asked to sort the cards into two groups according to as many different rules as possible with a maximum number of eight and to state the rule after each sort; (2) the examiner sorts the cards into two groups and the participant is required to report the rule used; (3) the participant is asked to sort the cards according to the abstract cues or explicit rules provided by the examiner. These conditions are repeated with each set of cards. As this format is a significant departure from that of the WCST, which is the topic of this thesis, further discussion of the California Card Sorting Test will not be undertaken.

Nelson (1976) made four modifications to the administration of the WCST procedure and three scoring modifications. First, all response cards sharing more than one attribute with a key card (e.g., colour and number) were eliminated leaving 24 cards: two packs of 24 cards are used. Therefore, verbal feedback to the participant on the correctness of the concept category chosen is unambiguous. Second, although the sorting rules are not disclosed, the participant is informed each time a rule is changed. Third, whereas the WCST categories are predetermined, in the modified WCST the first two categories are self-selected by the participant followed by the remaining third category; this order is then repeated. Finally, six rather than 10 consecutive correct responses are required before a rule change is implemented. Scoring includes the number of categories achieved, total number of errors, number of perseverative errors, failure to maintain set, and the total error score. Unlike Milner (1963), Nelson's definition of a perseverative error is a response that is the same as the previously incorrect response not a response that is the same as the immediately preceding category. A failure to maintain set is scored when an incorrect response occurs after three rather than six correct responses, and the total error score is the percentage of perseverative errors made.

Few comparative studies between the WCST and the modified WCST have been conducted. Shoqeirat, Mayes, MacDonald, Meudell, and Pickering (1990) compared the performance of patients with amnesia of various aetiologies and normal controls on both tests. Their results indicated that both tests were able to discriminate between patients and controls but that the WCST was more sensitive in discriminating between the amnesic groups. However, the tests were not directly comparable as performances on the WCST were compared to the manual norms whereas patient's performances on the modified WCST were compared to those of the controls. Order of presentation was also not counterbalanced, with the WCST administered first followed by the modified WCST two days later, therefore practice effects may have reduced the modified WCST's sensitivity.

Van Gorp and colleagues (1997) compared performance on the two card sorting tests in two clinical populations; a group of older adults with dementia (n=29 Alzheimer's Type & n=34 Vascular) and a younger group with HIV-1 (n=157). Their results indicated comparability between the tests on number of perseverative errors across both patient groups and also for the number of categories achieved for the younger group who were without severe cognitive impairment. For the number of failure to maintain set scores, however, both patient groups obtained higher scores on the WCST. Still, there were many methodological limitations that were recognised by the authors; a between-subjects design was used for both patient groups, there was no equivalence on measures of cognitive impairment or IQ between test groups, and the limited sample size did not provide sufficient power. The test groups were also highly unequal with twice as many dementia patients administered the modified WCST than the WCST and four times as many HIV patients administered the WCST than the modified WCST. Therefore, the findings require cautious interpretation.

Although methodological problems have limited the value of studies of comparability, the modified WCST has been found to adequately discriminate between patients with frontal lobe lesions and normal controls (see de Zubricaray & Ashton, 1996 for a review), to be sensitive to the early detection of dementia of the Alzheimer's type (Bondi, Monsch, Butters, Salmon, & Paulsen, 1993), and to be effective in detecting changes over time in the progression of degenerative illnesses or in monitoring the recovery of function from neurological insult (Lineweaver, Bondi, Thomas, & Salmon, 1999). Inasmuch as de Zubricaray and Ashton have suggested that the modified WCST should be considered a different test from the WCST because of the modifications, the modified WCST still requires participants to maintain information and to generate hypotheses about the sorting criteria, to compare feedback information to the current hypothesis on each trial, and to inhibit inappropriate responses from internal or external cues.

3.2 WCST as a marker of frontal lobe function

Following Milner's (1963) study, the WCST became widely used in neuropsychology as a measure of frontal lobe dysfunction and was considered specifically sensitive to dorsolateral frontal lobe pathology. In a review of studies in which the WCST had been administered to individuals with and without focal frontal pathology, Mountain and Snow (1993) proposed several conditions which they deemed as a requirement for the WCST to be considered a valid measure of frontal lobe dysfunction:

- performance on the test should be significantly poorer for frontal lobe patients than for nonfrontal patients or normal controls
- performance should be poorer for patients with dorsolateral lesions than for lesions in other frontal areas
- the test should be able to classify frontal patients, nonfrontal patients, and controls with a reasonable degree of accuracy

Their review compared studies of frontal lobe patients and controls, patients with frontal and nonfrontal damage, and patients with dorsolateral versus other frontal lesions. It revealed inconsistent findings with little evidence to indicate that the test's classification rate was superior to base-rate classification. Thus, the authors concluded that there was no strong evidence in support of the WCST as a sensitive or specific measure of frontal lobe dysfunction.

Since Mountain and Snow's (1993) review studies involving patients with known frontal lobe pathology have provided evidence for the sensitivity of the WCST to frontal lobe dysfunction although its specificity has remained unsupported. Arnett and colleagues (1994) examined 43 patients with multiple sclerosis and found that those with frontal white matter lesions achieved fewer categories and made more perseverative responses than those patients with minimal frontal lesions or controls. In a study investigating cognitive set shifting difficulties for 18 patients with obsessive-compulsive disorder Sanz, Molina, Calcedo, Martin-Loeches, and Rubia (2001) found a significant reduction in electrical changes in the prefrontal cortex. As previous neuroimaging studies had demonstrated activation of the frontal regions with WCST stimulation (see Volz et al., 1997) they interpreted the reduction as reflecting a dysfunction in the inhibitory pathway during WCST performance. Similarly, findings from a study in which functional magnetic resonance imaging (fMRI) was used to assess the cerebral activation of 13 patients with schizophrenia, indicated a lack of activation in the right prefrontal cortex during administration of the WCST compared with healthy controls (Volz et al., 1997).

Two well-conceptualised studies investigating the sensitivity and specificity of the WCST were conducted by Stuss et al. (2000) and Lombardi et al. (1999). Stuss et al. administered the WCST to 46 patients with single focal lesions under three different conditions: 128-WCST (Milner, 1963), 64-WCST in which the sorting criteria were disclosed, and 64-WCST in which a warning was given each time the criterion changed. To allow for greater specificity of the relationship between location and performance patients were assigned to one of four frontal groups (right dorsolateral, left dorsolateral, superior medial, inferior medial) or one of two nonfrontal groups (right, left). Their results indicated no significant difference in performance between patients with nonfrontal lesions and controls but showed consistent impairment on almost every measure for three of the four frontal groups (superior medial, and right and left dorsolateral). Perseverative errors and set loss accounted for the frontal effects, with the right dorsolateral group being the only group to maintain a high set loss across all three conditions.

Lombardi et al.'s (1999) study of eight closed head injured patients analysed not only the relationship between structural lesions on magnetic resonance imaging (MRI) and perseverative responses, but also the functional activation of frontal lobe and basal ganglia regions with positron emission tomography (PET) during perseveration. Their results showed that whilst a higher proportion of nonfrontal than frontal lesion patients committed an abnormally high number of perseverative responses, metabolic activation of the right dorsolateral prefrontal cortex and the right caudate nucleus significantly predicted the number of perseverative responses on the test. A hierarchical regression analysis also indicated a high degree of overlap in the proportions of variance accounted for by the two regions. Even though the sample size was small, the authors concluded that these results support the view that frontal and subcortical areas form part of an interconnected circuit, (Cummings, 1993; Royall et al., 2002). These and similar studies offer an explanation for the lack of specificity of the WCST as a marker of frontal lobe dysfunction and suggest that future studies investigating the localisation of cognitive processes should consider both the structural and functional integrity of brain regions rather than focussing on anatomical structures alone.

In summary, numerous studies involving a variety of clinical populations have provided evidence in support of the WCST as a sensitive measure of frontal lobe dysfunction, particularly with regard to the dorsolateral prefrontal region. Whereas its specificity has been debated for decades, a more recent understanding of the neural circuitry linking frontal and subcortical regions, as described in section 2.1, has provided an explanation for impaired WCST performance in patients with nonfrontal lesions. Advances in neuroimaging techniques have resulted in greater accuracy in localising brain lesions. Consequently, the focus of investigation into WCST performance, including the focus of the present thesis, has shifted from an anatomical to a functional perspective with efforts directed towards identifying cognitive processes underlying WCST performance, the relationship between index scores and cognitive processes, and the implications for rehabilitation.

3.3 Functions and processes underlying card sorting test performance

Owing to the multifactorial nature of the WCST many researchers have introduced modifications to the original test in order to explore the relationship between card sorting test performance, underlying cognitive processes, and associated neural networks. Modifications to both manual and computerised versions have included administering a set number of trials (Barceló, 1999, 2001; Barceló & Knight, 2002; Cinan & Tanör, 2002; Greve et al., 2002; Miyake et al., 2000; Nagahama et al., 2003; Stuss et al., 2000), eliminating all ambiguous cards (Barceló, 1999, 2001; Barceló & Knight, 2002; Miyake et al., 2000; Nagahama et al., 2003), disclosing the sorting criteria prior to commencement (Barceló & Knight, 2002; González-Hernández et al., 2002; Nagahama et al., 2003; Stuss et al., 2000), informing participants of a rule change (Cinan & Tanör, 2002; Stuss et al., 2000), using randomly determined categories (Barceló, 1999, 2001; Barceló & Knight, 2002), varying the number of trials per category (Barceló, 1999, 2001; Barceló & Knight, 2002), and providing a visual aid with feedback (Hartman, Steketee, Silva, Lanning, & Andersson, 2003; Monchi, Petrides, Petre, Worsley, & Dagher, 2001). Another modification, which appears to be incidental in most studies, is whether the previous response cards remain in view (Cinan & Tanör, 2002; Fristoe, Salthouse, & Woodard, 1997; Heaton, 1999) or are absent with each trial (Barceló & Knight, 2002; Cinan & Tanör, 2002; González-Hernández et al., 2002; Monchi et al., 2001), that is, whether visual feedback is or is not provided throughout the test. Cinan and Tanör's findings, in which a significantly higher number of errors occurred when visual feedback from previous response cards was present, would suggest that the presence or absence of visual feedback may be an important variable in WCST performance. The effect of visual feedback is further investigated in the current series of experiments.

Whilst some researchers have taken a behavioural approach to exploring the cognitive processes underlying WCST performance (Cinan & Tanör, 2002; Dunbar & Sussman, 1995; Glahn, Cannon, Gur, Ragland, & Gur, 2000; Stratta et al., 1997), others have used neuroimaging techniques (González-Hernández et al., 2002; Monchi et al., 2001), event-related potentials (Barceló, 1999), or statistical methods such as factor analysis (Fristoe et al., 1997; Greve et al., 2002; Paolo, Tröster, Axelrod, & Koller, 1995) or a latent-variable analysis (Miyake et al., 2000). Participants have included young and older adults with no neurological or psychiatric disorders (Barceló, 1999; Cinan & Tanör, 2002; Dunbar & Sussman, 1995; Fristoe et al., 1997; González-Hernández et al., 2002; Miyake et al., 2000) as well as patients with focal or diffuse intracranial lesions (Barceló & Knight, 2002; Wiegner & Donders, 1999), schizophrenia (Gold, Carpenter, Randolph, Goldberg, & Weinberger, 1997; Grön, 1998; Hartman et al., 2003; Stratta et al., 1997), schizotypy (Park, Holzman, & Lenzenweger, 1995; Tallent & Gooding, 1999), obsessive-compulsive disorder (Sanz et al., 2001), and dementia (Nagahama et al., 2003; Paolo et al., 1995).

In a series of studies Greve and colleagues investigated the processes underlying WCST performance using exploratory and confirmatory factor analyses. In their exploratory studies with survivors of traumatic brain injury (TBI) (n=161: Greve, Ingram, & Bianchini, 1998) and chronic severe TBI (n=68: Greve et al., 2002) the results indicated a three-factor solution (cognitive flexibility, problem-solving, response maintenance) for both the standard (up to six categories completed) and 128-card version of WCST. *Cognitive flexibility* was represented by the scores total correct, % conceptual level responses, categories achieved, perseverative errors, and perseverative responses; *Problem-solving* was represented by nonperseverative errors, and *Response maintenance* was represented by failure to maintain set scores. Wiegner and Donders (1999) also identified three factors, which they labelled response accuracy, learning, and failure to maintain set, in their study of 100 TBI patients (44=mild, 23=moderate, 33=severe). In contrast to the Greve et al. studies they used an oblique rather than an orthogonal rotation and their results indicated that nonperseverative errors were included in factor 1 (response accuracy) not factor 2 and the indices of trials to complete first category and learning to learn which were absent in the Greve et al. studies represented factor 2; failure to maintain set score, however, represented factor

3 in all studies. In a more recent confirmatory factor analytic study (Greve, Stickle, Love, Bianchini, & Stanford, 2005) involving 1221 neurological (n=620), psychiatric (n=228) and nonclinical control (n=373) participants, the three-factor model for the standard WCST was generally supported but the fit (CFI=.97; χ^2=59, p<.001) was not considered close enough to be a 'true' model. However, a one-factor model containing total correct, % conceptual level responses, perseverative errors, and categories achieved scores, representing a general measure of executive function, produced an excellent fit (CFI=1.0; χ^2=1.67, *p*=.20). From these and previous results the authors proposed a hierarchical structure in which successful performance on the WCST requires that the three relatively independent factors/processes are intact. That is, response maintenance (failure to maintain set) depends on an intact ability to problem-solve (factor 1 indices plus nonperseverative errors = factor 2), which in turn depends on the ability to shift set (factor 1). Therefore, the authors argued that the presence of a higher than average number of nonperseverative errors or failure to maintain set scores may indicate specific cognitive deficits whereas an absence of such scores may be less clinically meaningful in that the deficits are widespread.

Wiegner and Donders (1999) and Greve et al. (2002) also conducted regression analyses to determine cluster membership. In the Greve et al. study regression factor scores resulted in four clusters that represented higher than average failure to maintain set scores (cluster 1) which they interpreted as reflecting problems in attention, memory and/or impulsivity; impaired performance on the indices of the first two factors (cluster 2) as reflecting problem-solving and conceptual difficulties; extreme perseveration with few nonperseverative errors and a general inability to establish set (cluster 4) as reflecting gross cognitive impairment, and average or above scores on all indices (cluster 3) as reflecting relatively intact cognition. In contrast, Wiegner and Donders' analysis resulted in only two clusters in which the performance of participants in cluster 1 on all marker variables for each factor (% conceptual level responses, learning to learn, failure to maintain set) was worse than those in cluster 2. Further analyses indicated significant cluster effects ($p<.01$) for age at the time of injury, education, and length of coma whereas in the Greve et al. study there was only a significant effect for age at the time of injury ($p<.01$) and time of testing ($p<.05$). However, the participants in the Greve et al. study were survivors of severe TBI with a mean length of coma of 41.65 days whilst 44% of Wiegner and Donders' participants had mild TBI and the median length of coma for the severe TBI group was only two days. The differences in findings, therefore, maybe due to injury severity or to the variables used to represent each factor.

Wiegner and Donders' (1999) three-factor model was a replication of that found in a study investigating the construct validity of the WCST in normal elderly (n=187) and individuals with Parkinson's Disease (n=181: Paolo et al., 1995), although for the Parkinson's group nonperseverative errors and failure to maintain set scores loaded on the same factor. In the Paolo et al. study, when scores for the WCST and additional measures of memory (logical memory subtest of Wechsler Memory Scale, California Verbal Learning Test, Continuous Visual Memory Test) and attention (digits forwards and backwards) were submitted for factor analysis the results indicated the original three factors for the WCST scores plus a memory factor and an attention factor. As the WCST scores did not significantly load with either memory or attention for either group, the authors concluded that the WCST scores provide information on problem solving that is unrelated to memory and attention. Although there are no obvious methodological problems with this study, the conclusion is contrary to that of many other studies (Cinan & Tanör, 2002; Dunbar & Sussman, 1995; Gold et al., 1997; Konishi et al., 1999; Lehto, 1996; Monchi et al., 2001; Tallent & Gooding, 1999) that have argued for working memory and attentional processes as critical to successful WCST performance. Research investigating the relationship between working memory and WCST performance will be discussed in Chapter 5.

In another study, the contribution of three executive functions (shifting, updating and inhibition) to the performance on five complex executive tasks, including the WCST, was conducted at the level of latent variables (i.e., what is shared among the tasks for each executive function) rather than at the individual task level (Miyake et al., 2000). University students (N=134) completed nine tasks hypothesised to tap the executive functions of shifting (plus-minus task, number-letter task, local-global task), updating (keep track task, tone monitoring task, letter memory task), and inhibition (antisaccade task, stop-signal task, Stroop task) and five complex executive tasks including the WCST. Confirmatory factor analysis indicated a good fit for the two-path model (shifting and inhibition) for the WCST perseverative errors but also showed that the path from inhibition did not make much contribution once shifting had been taken into account. The researchers, therefore, concluded that shifting, defined as the "process [that] involves the disengagement of an irrelevant task set and the subsequent active engagement of a relevant task set" (p.55), is a crucial component of WCST perseverative errors. The three executive functions represented in this study are also discussed in Chapter 4 as functions of the central executive of working memory. As the representative tasks chosen all required the maintenance of goal-related information, Miyake et al. suggested that the commonality between shifting, updating, and inhibition might be the ability to actively maintain the information in working memory.

Some researchers, whilst acknowledging the role of working memory, have suggested that information-processing speed is the primary mediator in WCST performance. Fristoe et al. (1997) investigated the possible factors contributing to age-related differences in performance by administering computerised versions of the WCST, working memory tasks, sensorimotor speed and perceptual-comparison speed tasks to young (n=48, M=26.7 years) and older (n=49, M=70.1 years) adults. As well as the standard WCST, participants also completed an hypothesis generation procedure that required them to indicate the basis for their subsequent response. This enabled the researchers to quantify feedback usage. The results from hierarchical regression analyses and path analysis indicated that speed of processing accounted for age-related variance in card sorting performance (categories achieved, perseverative errors), the feedback usage index, and working memory measures.

Hartman et al. (2003) also examined the role of working memory and speed of processing in a sample of participants with schizophrenia (n=28) and age and education matched controls (n=28). Their results showed a significantly higher number of errors for the schizophrenia group and a significant relationship between WCST performance and working memory load. Nevertheless, when speed of encoding was controlled for group differences on categories achieved and number of nonperseverative errors were eliminated. The researchers suggested that working memory deficits impacting on card sorting test performance might involve a generalised inefficiency of information processing in individuals with schizophrenia.

Impaired performance on the WCST is determined by scores on one or more indices. One of the main aims in investigating the underlying cognitive processes of WCST performance is to develop a better understanding of which cognitive processes contribute to which index scores. Barceló (1999, 2001) argued that the use of the categories achieved and perseverative error indices as equivalent indicators of frontal dysfunction may have weakened the specificity of the WCST because nonperseverative errors, which represent an inability to maintain attention and inhibit interference from distracting stimuli, also result in a decrease in the number of categories achieved. He also proposed two types of nonperseverative errors; an *efficient error* defined as a shift to the wrong category in the second trial of a series due to an efficient trial and error strategy and a *random error* defined as a shift to a wrong category after negative feedback on all other trials. Barceló's rationale for these errors is that in the second trial only of a new series, the participant is faced with two possible correct rule choices. Therefore, a trial and error strategy is required. However, on the third and subsequent trials in the same series there is only one correct rule choice. To investigate the patterns of event-related potential activation of perseverative and random errors Barceló (1999) developed a computerised version of the WCST, known as the Madrid

Card Sorting Test (MCST). In a sample of university students (n=32) who had committed at least one perseverative or random error Barceló found separate, though complementary, patterns of activation, which suggests that the two types of errors result from disruptions in two different prefrontal neural networks. Whereas perseverative errors were associated with a reduction in P2 activity over the right frontal region and an absence of the extrastriate N1 component, random errors were associated with increased P2 activity over frontal-central regions. Barceló attributed the latter to "an untimely reset of the contents of working memory due to an inadequate inhibitory control of interfering stimuli" (p.4).

Barceló and Knight (2002) further investigated differences in perseverative, efficient, and random errors in patients with left lateral prefrontal focal lesions (n=6) and age and education matched controls (n=8). Although the prefrontal patients made significantly more random errors and significantly less efficient errors than controls, when these errors were combined and analysed as nonperseverative errors the group differences disappeared. Whilst prefrontal patients also made significantly more perseverative errors than controls, overall they produced more random than perseverative errors in 52% of the categories. These findings highlight the importance of random nonperseverative errors, postulated as reflecting working memory, attention, and inhibitory control processes, in determining successful performance on card sorting tests.

In summary, attention, information processing, cognitive flexibility, problem solving, inhibitory control, and working memory have all been identified as cognitive processes critical to successful WCST performance.

Factor analytic studies have produced one- and three-factor models with index scores loading on either a general factor or factors of cognitive flexibility, problem-solving, and response maintenance. Event-related potential studies have indicated that different neural networks contribute to perseverative and random nonperseverative errors which both influence the number of categories achieved. Working memory has been consistently cited as a critical process in card sorting test performance. However, the relationship between the different components of working memory and the index scores has not been fully investigated. Therefore, although the principal aim of the present thesis is to investigate the role of the different components of working memory in WCST performance, the relationship between working memory and the WCST index scores is also explored.

CHAPTER 4

Models of Working Memory

The term 'working memory' has been used by many cognitive psychologists to describe a system or systems whereby information is temporarily stored and processed during the performance of a range of complex cognitive activities (Andrade, 2001; Baddeley, 1986; Baddeley, Chincotta, & Adlam, 2001). In the past the term, 'working memory', was applied as a function of short-term memory (Atkinson & Shiffrin, 1968) but in 1974 Baddeley and Hitch proposed a multicomponent, limited-capacity system that enables information from different codes and different modalities to be maintained, integrated, and manipulated across a range of tasks (Baddeley, 1986). Although other models have since been proposed, the Baddeley and Hitch working memory model has been the most extensively researched and supported model to date (Andrade, 2001). Many studies investigating the cognitive processes underlying executive function tasks have suggested that working memory per se, or specific components of working memory, contribute to WCST performance. A detailed review of the WCST-working memory research, which is central to the present thesis, is presented in Chapter 5. But first, this chapter examines the evidence in support of the multicomponent model of working memory.

4.1 Structure of the working memory model

In the original working memory model (Figure 4.1a.) Baddeley and Hitch proposed a three-component system consisting of a limited capacity attentional system, the central executive, and two active slave systems, the

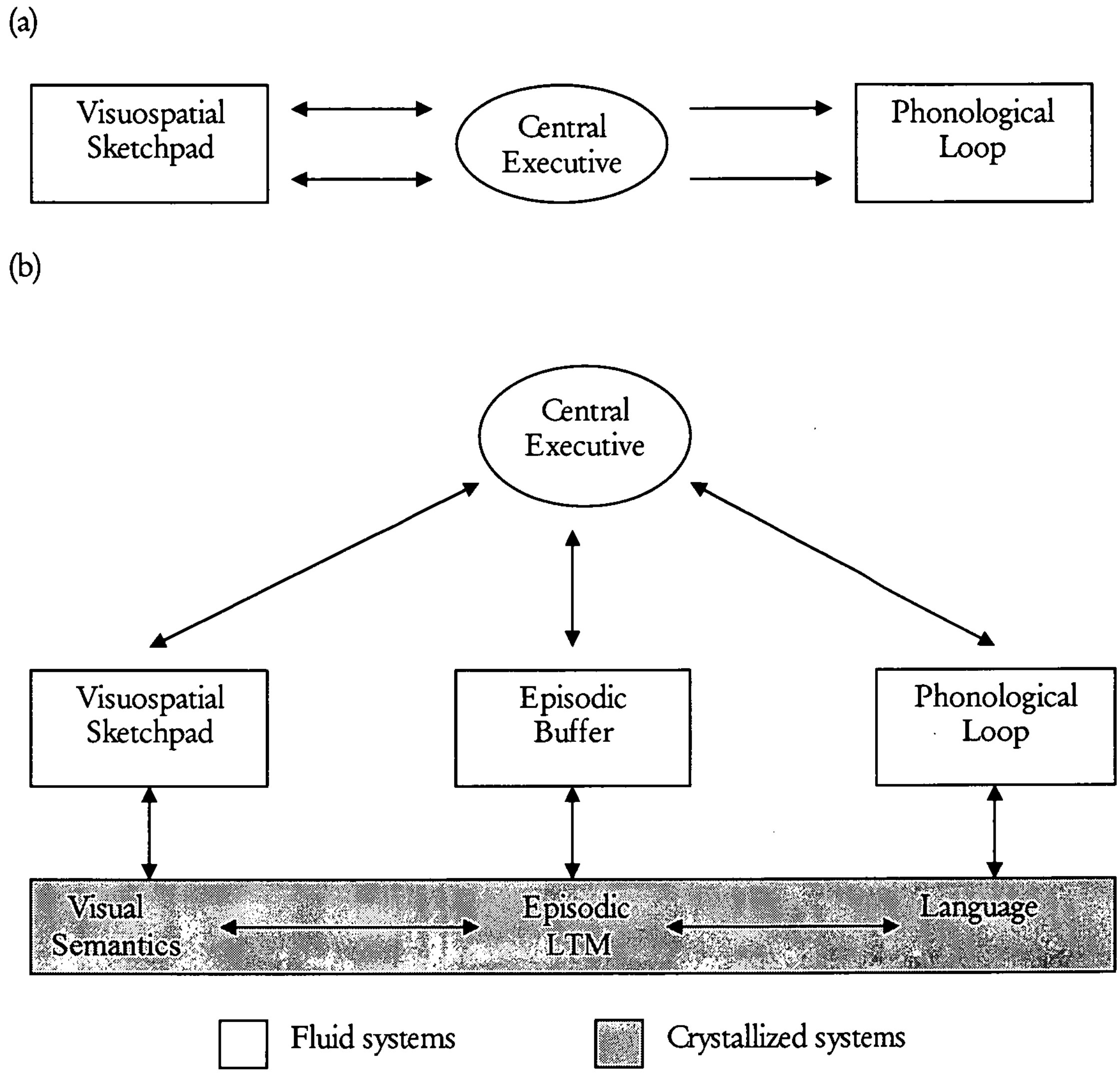

Figure 4.1. (a) The original Baddeley and Hitch three-component working memory model. (b) The revised and current working memory model incorporating the episodic buffer and links to long-term memory (LTM) (Baddeley, 2001).

phonological loop and the visuospatial sketchpad (Baddeley, 2000, 2001). The phonological loop is assumed to be responsible for the temporary storage and rehearsal of auditory and speech-based information. The visuospatial sketchpad is assumed to be capable of holding and manipulating visuospatial information. The third component, the central executive, was originally conceived as a limited-capacity attentional control system based on the supervisory attentional system model proposed by Norman and Shallice (1986). Although the central executive initially functioned as a homunculus subsequent research has provided evidence suggesting that it can be fractionated into multiple subsystems (see Baddeley, 2001). More recently Baddeley (2000) reformulated the original model with the addition of a fourth component, the episodic buffer (Figure 4.1b). The episodic buffer is assumed to be a limited-capacity temporary storage system, which is controlled by the central executive and provides for the integration of information from the slave systems and long-term memory. In this model the central executive is considered to be purely a processing system with the capacity to influence the content of the buffer by attending to a variety of sources (perceptual, working memory subcomponents, long-term memory) and with the ability to retrieve information from it "in the form of conscious awareness, of reflecting on that information and, where necessary, manipulating and modifying it" (p.421).

The addition of the episodic buffer to the model arose from a need to address research results that proved problematic for the original three-component model. For example, the contrast between the typical unrelated word span of five or six words and a span of 16 or more when the words comprise a meaningful sentence; the enhancement of recall by chunking; the ability for information from the two slave systems to be combined as evidenced by patients with impaired short-term phonological memory who recall more digits when they are presented visually; the role of conscious awareness, and the contribution of long-term memory in storing complex images (Baddeley, 2000, 2001). Unlike the array of research findings in support of the original three components of the working memory model, the concept of the episodic buffer is still in its infancy and has yet to be fully developed. No further review will be undertaken of this component as it is beyond the scope of the present thesis.

4.2 Experimental methods of investigating working memory

Before reviewing the different components of working memory it helps to understand the methods that have been employed in investigating the strength of the model. The main strategy used in studies of both clinical and nonclinical populations, including within the present series of experiments, has been the dual-task paradigm. As the concept of working memory is that of a limited capacity system analogous to short-term or primary memory Baddeley (1986) hypothesised that the most logical strategy to use was the introduction of a supplementary or secondary task which would occupy a substantial amount of that capacity. If two tasks are competing for the same limited storage space then there should be a deterioration in performance when the tasks are performed concurrently, in contrast to when they are performed individually. In studies exploring the phonological loop, articulatory suppression in which one word (e.g., ‘the’, ‘blah’, ‘double-double’, ‘Monday’) is repeated constantly at a rate of approximately three or four words per second, has been the most commonly used strategy to prevent subvocal rehearsal of either auditory or visually presented stimuli (Baddeley, Lewis, & Vallar, 1984). Spatial movement, such as sequentially touching an array of keys or pegs (spatial tapping), has been found to consistently disrupt performance on a visuospatial task (Baddeley & Lieberman, 1980; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Logie & Marchetti, 1991) and secondary tasks that incur a greater memory load or require greater attentional input, such as randomly generating numbers or repeating a sequence of alternating numbers and letters (verbal trails), have been used to explore the central executive (Baddeley, 1996; Baddeley, Emslie, Kolodny, & Duncan, 1998). Irrelevant and/or unattended pictures, speech, and noise have also been used as secondary tasks in studies investigating the nature of stored representations (Logie & Marchetti, 1991; Salamé & Baddeley, 1982; Zimmer & Speiser, 2002).

Statistical methods, such as correlational and regression analyses, have been used in studies of individual differences in working memory (Daneman & Carpenter, 1980) and those exploring the development of working memory in children (Gathercole & Baddeley, 1989; Swanson, 1999). Other approaches, which have enabled researchers to investigate dissociations in performance on a variety of working memory and other cognitive tasks, have involved patients with brain lesions that have selectively affected some aspect of working memory (Dunbar & Sussman, 1995) or have involved a population with suspected central executive deficits, such as patients with dementia (see Baddeley, 2002). Neuroimaging techniques (PET; fMRI), which reveal brain activation during the performance of tasks, have also contributed to an understanding of the anatomical locations and neural networks involved in working memory (Awh & Jonides, 2001; Cabeza, Dolcos, Graham, & Nyberg, 2002; Collette & van der Linden, 2002).

4.3 Phonological loop

Of the components of working memory the phonological loop has received the most attention from researchers and is the best substantiated. It purportedly comprises two subcomponents; the *phonological store* which holds memory traces of auditory and speech-based material that fade within approximately two seconds unless refreshed and the *articulatory rehearsal system* which maintains the memory trace by subvocal rehearsal (Baddeley, 1992, 2000, 2001). The articulatory rehearsal system also enables visually presented material to be phonologically recoded for access to the phonological store (Vallar & Papagno, 2002). Evidence in support of the function of the phonological loop has been provided by such phenomena as the phonological similarity effect, the irrelevant speech effect, the word length effect, and articulatory suppression. The phonological similarity effect has been observed when the immediate recall of words has been poorer for similar sounding items (e.g., man, cap, can, map, mad; B, V, G, T) than for dissimilar items (e.g., pit, day, cow, pen, rig; F, K, Y, W) with no such effect occurring when there is a similarity of meaning (Baddeley, 1966; Conrad & Hull, 1964). Irrelevant speech in a foreign or native language, or with words comprising the same number of phonemes has been shown to disrupt immediate serial recall whereas white noise, nonvocal music, or phonologically dissimilar words have not (Colle & Welsh, 1976; Salamé & Baddeley, 1982, 1987). The word length effect in which immediate serial recall is inversely related to word length has been demonstrated in studies using English words (Baddeley, Thomson, & Buchanan, 1975) and in comparative studies of foreign languages where words with the same meaning vary in their spoken duration (see Baddeley, 1992). The phonological similarity and irrelevant speech effects suggest that the phonological store relies on a phonological code with the provision for direct access whereas the word length effect provides support for the notion of a subvocal rehearsal system in maintaining material within the store.

Baddeley and Lewis (1984) further investigated these effects in a series of five experiments using articulatory suppression. Their results indicated that the phonological similarity effect was unaffected by articulatory suppression whereas the word length effect was abolished by it, thereby providing support for the concept of the phonological loop as comprising two subcomponents, a phonological store and an articulatory rehearsal system.

As visually presented material has been shown to engage the articulatory rehearsal system, it is not unreasonable to assume that subvocal rehearsal could be used to maintain information regarding the sorting criteria and previous responses during WCST performance. If so, then concurrent use of articulatory suppression during the completion of the task, which is used in Experiment 3, should result in poorer performance (i.e., fewer categories achieved, more errors).

4.4 Visuospatial sketchpad

The concept of a visuospatial sketchpad has received support from studies that have shown clear dissociations between performances on verbal and visuospatial tasks. Farmer, Berman, and Fletcher (1986) found that continuous sequential tapping disrupted performance on a spatial reasoning task but had no effect on a verbal reasoning task whereas the reverse occurred with articulatory suppression. Spatial tapping but not articulatory suppression has also been shown to interfere with performance on the Corsi Blocks (Smyth, Pearson, & Pendleton, 1988), and on the construction phase but not the verbal recall phase in a creative synthesis task (Pearson, Logie, & Gilhooly, 1999). In a series of experiments using positron emission tomography Smith, Jonides, and Koeppe (1996) showed a double dissociation in which verbal activities primarily activated the left hemisphere regions whereas spatial tasks only activated right hemisphere regions. A dissociation between working memory components was also found in a single case study of a 54-year-old female who had suffered a right hemisphere aneurysm (Hanley, Young, & Pearson, 1991). Although her performance on spatial tasks such as the Corsi Blocks and Brooks Matrix were significantly impaired, her immediate recall of letters presented in either the visual or verbal modality was unaffected. Additionally she showed effects of phonological similarity and articulatory suppression, which suggests an impairment of the visuospatial but not phonological component of working memory.

Empirical studies designed to investigate the visuospatial sketchpad have proved to be more difficult than for the phonological loop. Baddeley initially concluded that the visuospatial sketchpad was primarily spatial following his and Lieberman's (1980) study in which concurrent spatial activity (blindfolded tracking of a pendulum using auditory feedback) disrupted performance on the Brooks' Matrix but a concurrent visual activity (judging the brightness of slides) did not. However, subsequent studies have found that the effect of visual and spatial secondary tasks is dependent on the visuospatial primary tasks used (for a review see Zimmer & Speiser, 2002). For example, Logie and Marchetti (1991) investigated the effects of a spatial tapping task and presentation of irrelevant line drawings during the retention interval in a recognition memory study. The primary task involved the sequential presentation of coloured squares. After the retention interval in the spatial condition participants were to decide if the location of the squares had changed whereas in the visual condition they were to decide if the shade of one of the coloured squares had changed. The results indicated a double dissociation with the spatial memory task being disrupted by the spatial tapping task but unaffected by the line drawings, whilst performance on the visual memory task was disrupted by the line drawings and unaffected by the tapping task. The visuospatial sketchpad has also been shown to be susceptible to a visual similarity effect if the verbal recoding of visually presented material is prevented (Hitch, Woodin, & Baker, 1991) or the material cannot be verbalised (Hue & Ericsson, 1988). Such results suggest that the visuospatial sketchpad maybe analogous to the phonological loop and comprise two subcomponents. However, unlike investigations of the phonological loop the functions of these subcomponents have proven more difficult to define.

4.5 Fractionation of the visuospatial sketchpad

There appears to be a consensus among researchers that there are at least two subcomponents comprising the visuospatial sketchpad. Divergent opinions, however, arise as to the nature of those components; whether they can be defined on the basis of visual versus spatial, active versus passive, or dynamic versus static; whether the visual component represents the storage of visuospatial material whilst the spatial component represents the rehearsal of material, or whether each component reflects both storage and rehearsal depending on the nature of the visuospatial material.

The visual-spatial dichotomy has evolved from research into the primate and human visual systems which have provided evidence for two visual streams; the *magnocellular* stream which selectively processes movement and spatial information and the *parvocellular* stream which selectively processes information about form, including colour and orientation (Breitmeyer, 1992). An anatomical distinction between visual and spatial working memory has been shown in positron emission tomography (Courtney, Ungerleider, Keil, & Haxby, 1996; Smith et al., 1995) and repetitive transcranial magnetic stimulation studies (rTMS: Mottaghy, Gangitano, Sparing, Krause, & Pascual-Leone, 2002). Specifically, spatial tasks have activated the dorsal streams in prefrontal and extrastriate areas, whereas visual tasks have activated the ventral streams in these areas. Furthermore, occipital and parietal regions show involvement with spatial tasks, in contrast to inferotemporal and parietal regions with visual tasks.

A functional distinction between visual and spatial working memory has been indicated by differing developmental trends (Logie & Pearson, 1997; Vicari, Bellucci, & Carlesimo, 2003) and behavioural studies (Della Sala et al., 1999; Hecker & Mapperson, 1997; Tresch, Sinnamon, & Seamon, 1993). Vicari and colleagues conducted two recognition memory studies involving a group of normally developing children (n=202) and children with Williams syndrome (n=13). Williams syndrome is characterised by a cognitive profile that includes impaired spatial abilities with relatively intact visual-perceptual abilities. For the normally developing children they found that visual span only increased significantly from 7 to 10 years whereas spatial span increased significantly and incrementally from 5 to 10 years. For children with Williams syndrome they found that spatial span was lower on average than that for normally developing age-matched controls, but that visual span was comparable in both groups. These results suggest that the tasks relied on different cognitive systems. Hecker and Mapperson used concurrent unattended interference stimuli in the form of black and white versus coloured flicker to show a double dissociation in performance on a matrix task in which participants were required to recall the location of squares in order of presentation (spatial condition) or to indicate from a display the order of presentation of colours/arrows (visual condition).

Della Sala et al. (1999) also found a double dissociation when they compared performance on the Visual Patterns Test and Corsi Blocks, with and without selective interference tasks. The Visual Patterns Test consists of a series of grids in which half of each grid is filled to create a visual pattern that is very difficult to verbally encode. The grids progress in size, and therefore complexity, from a 2 x 2 grid (with 2 filled cells) to a 5 x 6 grid (with 15 filled cells). There are three grid patterns at each level of complexity and each pattern is presented for 3 s. Visual working memory span is determined by the level of complexity of the largest grid where at least one of the three patterns is correctly recalled. For the visual interference task in this study participants viewed an array of irrelevant abstract paintings presented within a 10 sec delay prior to recall. The Corsi Blocks consists of nine wooden blocks unevenly distributed over a flat board. The experimenter taps a sequence of blocks at a set rate and the participant is required to tap out the same sequences. The difficulty level is raised by increasing the number of blocks tapped. There are three trials at each level and spatial span is determined as the longest sequence achieved in which two out of the three sequences is correctly recalled (Della Sala et al., 1999). For the spatial interference task in this study participants were required to touch an unseen square pattern of pegs presented within a 10 sec delay prior to recall. The results indicated that although both visual and spatial spans were shortened by the interference tasks, the reduction of span with the spatial interference task was significantly greater for the Corsi blocks than for the Visual Patterns Test ($p<.001$) whereas the reverse effect occurred with the visual interference task ($p<.001$).

As well as storing information about static visual patterns Logie, Della Sala, Wynn, and Baddeley (2000) showed that the visual store can also hold sequential information. When participants were shown lists of phonologically similar words that were either visually similar (FLY, PLY, CRY, DRY) or visually dissimilar (GUY, THAI, SIGH, LIE) they found that the visually dissimilar lists were recalled more accurately than the visually similar lists. These findings may have relevance for the retention of visual information in the WCST, to be explored in the following experiments, as it involves the sequential presentation of the response cards.

McConnell and Quinn (McConnell & Quinn, 1996; McConnell & Quinn, 2000; Quinn & McConnell, 1996) found a dissociation between visual and spatial processing using dynamic visual noise concurrently with visual imagery tasks (pegword mnemonic, and method of loci). Andrade and colleagues (Andrade, Kemps, Werniers, May, & Szmalec, 2002) also found an effect of dynamic visual noise on pegword imagery. However, they found no such effect on working memory tasks involving static matrix patterns or Chinese characters and concluded that different cognitive processes may underlie visual working memory and visual imagery. Logie (1995) also suggested that working memory and visual imagery are not synonymous but that working memory is the structure that enables imagery to be carried out. Therefore, further discussion of the imagery literature will not be undertaken here, as the present thesis is specifically concerned with working memory.

In contrast to the visual-spatial distinction Pickering, Gathercole, Hall, and Lloyd (2001) suggested that it is the static and dynamic nature of the tasks rather than the visual and spatial properties that tap different components of the visuospatial system. In a series of experiments with children 5-10 years (total n=104) and adults (n=12) they used computerised tasks, similar to the Visual Patterns Test and Corsi blocks, which they proposed were static and dynamic versions of matrices, and paper and pencil mazes. In the static maze condition participants were presented with a completed route through the maze and in the dynamic condition the experimenter demonstrated the route by tracing it with the child's finger. Their results showed a developmental dissociation but in contrast to the aforementioned study of Vicari et al. (2003), span on the static versions increased more steeply with age than on the dynamic versions. In the subsequent experiments in which only the matrices were used they found that concurrent spatial tapping impaired performance on both static and dynamic versions for children but only on the dynamic version for adults. Although the authors interpreted their findings as evidence for the static and dynamic nature of information in short-term memory, spatial processing by definition includes localising points in space and perceiving motion (Logie, 1995). Additionally, it does not explain dissociations on visual and spatial tasks in studies where the spatial task involves location without movement (Darling, Della Sala, Logie, & Cantagallo, 2006; Owen, Morris, Sahakian, Polkey, & Robbins, 1996; Tresch et al., 1993).

For example, Darling et al. (2006) recently reported data from a study which suggested that information for location and appearance is processed by different subsystems even without the sequential versus simultaneous presentation. The study involved two brain-injured patients with selective memory deficits for location (patient A) and appearance (patient B), five age and sex matched healthy controls for each patient, and 15 brain-injured controls. All participants were presented with 30 randomly positioned white squares on a black computer screen. A letter P in a typeface randomly selected from a set of 433 examples was presented for 500 ms in one randomly selected square. Following a delay interval of 500 or 15500 ms, participants were instructed to indicate whether a probe letter P was of the same or different appearance (appearance condition) or in the same or different location (location condition) as that originally displayed. Patient A's performance on the appearance task was indistinguishable from controls but his performance on the location task was 3 SD below that of the controls after a 15500 ms delay. In contrast, patient B's performance on the location task matched that of the controls but on the appearance task was worse after 500ms delay and greater than 3 SD below the means after 15500 ms. These results, therefore, suggest that " the segregation of visuo-spatial working memory into visual and spatial components does not solely rely on a contrast between simultaneous and sequential presentation of stimuli" (p.179).

Another perspective on the visual-spatial distinction has been offered by Vecchi and colleagues (Vecchi, 1998; Vecchi & Cornoldi, 1999; Vecchi & Girelli, 1998) who argue for a passive-active distinction whereby visuospatial working memory tasks are located on a continuum. In contrast to the visual-spatial and static-dynamic views, they propose that the Corsi blocks and Visual Patterns Test are both passive measures as encoding and recall are in the same format, whereas tasks such as mental rotation and image subtraction which require participants to modify, integrate, or transform information are active measures of visuospatial working memory. However, in reference to Baddeley's multicomponent model of working memory the passive-active distinction appears to simply reflect the roles of the visuospatial sketchpad and the central executive respectively, rather than subcomponents of the visuospatial sketchpad. It also does not provide an explanation for the double dissociations found between performance on the Corsi blocks and Visual Patterns Test as previously described.

In a series of behavioural and neuroimaging studies, Awh and colleagues provided evidence which suggests that the active rehearsal of spatial information in working memory is achieved by a shift in attention to memorised visual locations (for a review see Awh & Jonides, 2001). For example, in one study they found that when a retention interval task that directed the participants' attention to the memorised location was performed, reaction times for the task were reliably faster than when participants' attention was directed to a different location. This effect was not observed when participants were required to remember the identity rather than the location of the cue item. They also found decrements in memory performance when participants performed a colour discrimination task during the retention interval that required a shift in attention because of the size and eccentricity of the secondary stimuli. Performance remained unchanged when the secondary stimuli occluded all potential memorised locations, which eliminated the need for an attentional shift. Smyth (1996) found impaired performance on the Corsi blocks when participants were required to fixate a central target during the retention interval and performance of a secondary task. This suggests that interference in the rehearsal of spatial working memory is due to shifts in attention and not simply eye movements. Event-related potential and functional magnetic resonance imaging studies have also indicated a functional overlap between spatial working memory and spatial selective attention. Increased contralateral activations found in studies of spatial attention have been observed on tasks requiring the memorisation of locations (Awh et al., 1999). Additionally, similar evoked responses to these tasks have been found in a direct comparison between the effects of spatial rehearsal and spatial attention to identical visual stimuli (Awh, Anllo-Vento, & Hillyard, 2000). Curtis and D'Esposito (2003) in their review of studies into the role of the dorsolateral prefrontal cortex in working memory have also hypothesised that observed concurrent activations of the frontal eye fields and dorsolateral prefrontal cortex during spatial working memory tasks may represent covert motor expressions which reflect the repetitive focusing of attention on to-be-remembered items.

Correspondingly, there is evidence to suggest that visuospatial working memory is more closely linked with central executive functioning or controlled attention than is verbal working memory (Fisk & Sharp, 2003; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Fisk and Sharp investigated the involvement of executive processes in spatial movement sequences using a visuospatial running memory task. On this computerised task participants were presented with a 10-celled matrix in which between 4 and 10 cells were sequentially highlighted. The list length of each trial was unknown to the participant who was required to serially recall the last four cells highlighted. Secondary tasks included a simple tapping task, a spatial tapping task, and random letter generation, a task known to load on executive resources. Their results showed a greater degree of disruption in performance of the primary task with random generation than for either of the other two secondary tasks. In a follow-up study they included as a secondary task alphabetic generation to control for the possibility that random generation interfered with phonological rather than executive processes. Results again indicated greater disruption with random generation, which suggests that the central executive is involved during the processing of spatial sequences.

Dissociations are consistently being found in studies researching visuospatial working memory. Although there is still debate as to whether these dissociations are due to different cognitive components, different processes, or are due to the characteristics of the tasks being used, the majority of evidence appears to support a visual-spatial dichotomy.

4.6 Role of the central executive

As mentioned previously, when the working memory model was first conceptualised the role of the central executive, albeit temporarily, was as a homunculus (Baddeley, 1996, 1998, 2002). Since then Baddeley and colleagues have attempted to specify some of the functions performed by this multifunctional component. As well as support for the central executive being a purely processing system with no storage capacity (Duff, 2000), one function has so far been identified; the function of dual-tasking or divided attention. In studies of patients with Alzheimer's disease and young and age-matched elderly adults, Baddeley and colleagues (see Baddeley, 2002) investigated dual task performance using a verbal task (digit span) and a visuospatial task (pursuit tracking), or a visual search task and auditory detection task. The results indicated that even when the level of difficulty for the individual tasks was titrated so that all participants were performing at the same level of accuracy, only in the Alzheimer patients was there a significant decline in performance when the tasks were performed concurrently. To determine whether this deficit was due to differences in speed of processing, further studies were conducted in which the difficulty level for these tasks was increased (Logie, Cocchini, Della Sala, & Baddeley, 2000, cited in Baddeley, 2002) or performance on simple and choice reaction times were compared (Baddeley, Baddeley, Bucks, & Wilcock, 2001). Increased difficulty levels for the individual tasks had the same effect on all three groups. Although processing speed was found to be slower for the older participants, overall there was no interaction between disease (with or without Alzheimer's) and level of difficulty (simple vs choice reaction times). As dementia of the

Alzheimer's type is associated with impaired episodic long-term memory and working memory, and a deficit in dual task performance is not a characteristic of normal elderly adults, Baddeley (1996, 1998, 2002) proposed that this provides evidence of a dual task function for the central executive.

In a study with a more practical orientation A. Hartman, Pickering, and Wilson (1992) explored the implications for physiotherapy for a group of head-injured patients with a central executive deficit (n=25) and a control group of orthopaedic patients (n=25). Performance on a primary tracking task was compared when performed alone and concurrently with digit span, verbal feedback (e.g. 'try to catch up with the target') and conversation. Their results showed performance by the head-injured patients was markedly impaired when the primary task was combined with concurrent conversation by the therapist whereas the orthopaedic patients experienced no interference effects. No other significant differences between the groups were found.

Other functions attributed to the central executive are task switching, focussed selective attention, and updating. However, evidence in support of these has not been as forthcoming or as substantial as for dual tasking. A study investigating task switching (Baddeley, Chincotta et al., 2001) used an arithmetic task in which participants were presented with a list of single digits and asked to either add 1 or subtract 1 from each digit. In the two task-switching conditions (with and without plus and minus signs) they were required to alternate between adding and subtracting as they moved through the list. The secondary tasks used were modified verbal trails (Monday, January, Tuesday, February, etc.) and articulatory suppression (the, the, etc.). Although performance in the switching conditions was markedly affected by concurrent verbal trails, performance in the non-switching conditions was also impaired but to a lesser extent. In contrast, articulatory suppression interfered with performance in the switching conditions only which the authors interpreted as representing maintenance of the switching program itself. Baddeley et al. conceded that whilst the results provide some support for a role of the central executive in task-switching the impact of the secondary task (verbal trails) in the non-switching conditions warrants further investigation.

Focussed selective attention, as a function of the central executive, has not been very widely researched. Defined as "the capacity to attend selectively to one stream of information while discarding others" (Baddeley, 1996, p.19) Baddeley investigated selective attention in a group of 24 middle-aged (mean age=42 years) and 24 elderly (mean age=72 years) adults. In a series of three experiments participants were presented with auditory (tone, squeak, or grunt) and visual (circle, triangle, diamond, or square) stimuli and were required to respond by pressing a key when the designated target stimulus appeared. Overall, conditions included responding when the stimulus was presented alone, with irrelevant stimuli in the same dimension (responding to circles but ignoring triangles; responding to a squeak but ignoring a grunt), or with irrelevant stimuli in a different dimension. All participants were slower at responding in the presence of irrelevant stimuli and the elderly participants were consistently slower than the middle-aged participants. Nonetheless, after IQ differences and speed of processing had been partialled out reaction time for the elderly participants was significantly slower when they were required to ignore a stimulus in the same dimension but not when the stimulus was in a different dimension. As studies have shown decrements in working memory with ageing, these results suggest that the ability to inhibit distracting information and focus selectively also declines with age and provides tentative support for selective attention being a function of the central executive (Baddeley, 1996). In the WCST, previous response cards remain on view. This means participants are confronted with stimuli (shapes, colours) in the same dimension that require inhibiting so as to correctly match the next response card to the appropriate key card and not to a previous response card. A higher number of errors, therefore, would be expected in the presence of a deficit in focussed selective attention.

In the reformulated version of the working memory model, the central executive is postulated as a processing system with no storage capacity. Duff (2000) investigated this claim by comparing participant performances on single and combined storage tasks and single and combined processing tasks. In the storage experiment university undergraduates (n=20) were administered a visually presented digit span that required oral recall (phonological loop storage task) and a computerised modified version of the Corsi blocks (visuospatial sketchpad storage task) that required serial recall of the activated squares to be marked on pre-prepared data sheets. In the dual storage task the randomly activated squares of the visuospatial sketchpad task contained numbers, which were to be orally recalled simultaneously with completion of the data sheets. As expected the dual tasking did not significantly reduce performance on either task compared to the single task conditions thereby supporting the concept of two independent storage systems. In the processing experiment undergraduates (n=17) were aurally presented with lists of monosyllabic words and non-words to which they were to repeat only the real words (phonological loop processing task). For the visuospatial sketchpad processing task participants were required to locate and respond to randomly generated targets on a computer screen by positioning the cursor and clicking on the target. The dual task required performing these two tasks concurrently. The results showed a non-significant decline in performance from single to dual task for the phonological loop processing task and a significant decline in performance from the single to dual task for the visuospatial sketchpad processing task, which suggests the existence of a shared component for processing material from both modalities, namely the central executive.

Doiseau and Isingrini (2005) examined the process of updating as a function of the central executive in a factor analytic study involving 50 older adults (mean age=77.9). Participants were aurally presented with lists of between 6 and 11 consonants and were required to remember serially only the last six items. Their results produced a two-factor model, which they interpreted as reflecting verbal storage or the phonological loop (Factor 1) and an updating process or the central executive (Factor 2). Factor 2 was significantly correlated with the WCST index scores of categories achieved, total errors, and perseverative errors, which was the only task used as a measure of executive function. Even though the sample size is small for a factor analytic study, the results are consistent with those of Morris and Jones (1990) who found a dissociation between a memory-load component and an updating process component when they examined the effect of articulatory suppression and irrelevant speech on the same running memory task. They found that both interference tasks disrupted performance on serial recall (phonological loop involvement) but not on the updating component (central executive involvement); and updating memory disrupted performance independently of the effects of the interference tasks.

Neuroimaging studies have attempted to define the anatomical location of the central executive (for reviews see Andrés, 2003; Collette & van der Linden, 2002). In one fMRI study in which the neural substrates of dual-tasking were explored using a semantic judgement task and spatial rotation task, a significant increase in activity was found bilaterally in the dorsolateral prefrontal cortex and anterior cingulate in the dual-task condition but not during the single task conditions (D'Esposito, Detre, Alsop, & Shin, 1995). However, the majority of studies have found no specific dependency on the prefrontal cortex for dual-task coordination but rather the suggestion that cerebral areas already activated in the single task conditions interact when dual-tasking is required. Klingberg (1998) used positron emission tomography to measure regional cerebral blood flow during the single and dual-task performance of an auditory working memory task and a visuospatial working memory task. Although the tasks activated sensory-specific areas in the superior temporal gyrus and occipital pole respectively, both tasks activated areas of the dorsolateral prefrontal cortex, inferior parietal and cingulate cortex with no cortical area activated only in the dual task condition. It could therefore be argued that the overlapping areas of activation during dual tasking represent the processing function of the central executive.

4.7 Logie's model of working memory

Much of the preceding research reviewed is also applicable to Logie's (1995, 2003) model of working memory, which parallels Baddeley's tripartite model. The conceptual similarities are not surprising given that Baddeley and

Logie have collaborated on numerous working memory projects (e.g., Baddeley & Logie, 1999; Logie et al., 2000).

As illustrated in Figure 4.2, Logie's model comprises a pair of components (phonological store, inner speech) analogous to the phonological loop, a pair of components (visual cache, inner scribe) analogous to the visuospatial sketchpad, and a central executive component (executive functions) involved in the coordination and manipulation of information in the temporary memory and rehearsal systems, including information generated from the knowledge base of long-term memory (Logie, 2003). Logie, however, has been more explicit in his concept of the visuospatial sketchpad in which he describes a passive visual store, the *visual cache*, and an active rehearsal mechanism, the *inner scribe*. The visual cache is assumed to store information about the appearance and layout of a visual scene involving form, colour, and orientation. The inner scribe is assumed to be a rehearsal mechanism for the retention of movement sequences and to be linked to the planning and execution of movement. Although the visual cache and inner scribe are theoretical functional concepts, they may be anatomically associated with the parvocellular and magnocellular streams, respectively, described in section 4.5.

A distinctive feature of Logie's model is that activation of representations in long-term memory are required for information to enter the working memory system with no direct access available from the perceptual systems. He suggests that sensory information about edges, contours, shades, and textures are identified as shapes and objects in long-term memory, based on the knowledge of past experiences, before the information is retained and

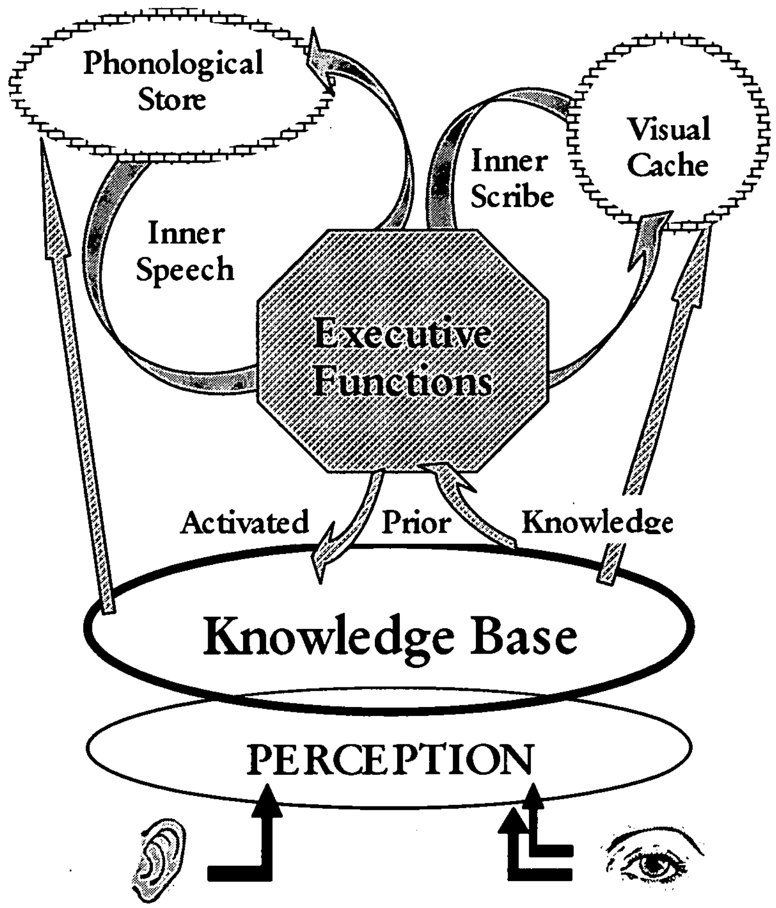

Figure 4.2. Logie's multiple component model of working memory (Logie, 2003)

manipulated in the working memory system. For example, reinterpreting ambiguous figures or creating a new design from well-known shapes or objects has been shown to be difficult unless alternative interpretations based on prior knowledge can be accessed (see Logie, 2003 for a review). Working memory then "acts as the workspace to manipulate the information and seek some means to resolve ambiguities or generate new knowledge" (p.50).

4.8 Link between working memory and executive functions

Neuroimaging studies have revealed a commonality of structures involved in performance of tests of executive function and those specific to working memory. In particular, the dorsolateral prefrontal cortex that has been identified as belonging to one of the three prefrontal circuits relevant to executive functioning (see Chapter 2) has also been shown to be activated during performance of tests of spatial attention and those tapping all components of working memory. Nonetheless, high correlations between executive tasks have not been found (Baddeley, Della Sala, Papagno, & Spinnler, 1997; Lehto, 1996; Miyake et al., 2000; Miyake et al., 2001) which suggests that the contribution of working memory to successful performance on executive tasks is not uniform and may vary depending on task requirements (Baddeley et al., 1997; Kimberg & Farah, 1993).

In a comparative study of the WCST, the Tower of Hanoi, and a Goal Search Task, Lehto (1996) found that only the WCST was significantly correlated with a range of nine simple-span and complex-span working memory tasks. In addition to the WCST index scores of number of categories achieved, total number of errors, number of perseverative responses, and number and percentage of perseverative errors calculated, two new scores were developed; total number of trials and the average number of cards needed to complete a category. The score that showed the most extensive correlations with the working memory tasks was the total number of trials, which were all significant at the 5% level. Perseverative measures were only significantly correlated with the aggregate complex span score although Lehto speculated that for a normal population this might be too crude a measure.

Gilhooley, Wynn, Phillips, Logie, and Della Sala (2002) examined the contribution of both visuospatial and verbal working memory in performance of the five-disc Tower of London task. Consistent with Lehto's results on the Tower of Hanoi they found no evidence of verbal working memory involvement. However, their factor analytic results indicated that performance on the Tower of London is mediated by visuospatial working memory. As the largest loadings were associated with the Corsi tasks the researchers further suggested that performance was contingent not only on visuospatial working memory but more specifically on the active spatial rehearsal mechanism, the inner scribe.

Miyake and colleagues (Miyake et al., 2001) also investigated the relationship between spatial abilities and executive functioning, represented by the Tower of Hanoi and Random Number Generation. However, they classified the Corsi Blocks as a short-term memory task rather than a working memory task even though its procedure is analogous to the Digit Span. The second visuospatial short-term memory task they used could also be classified as a working memory task (Dot Memory) as the procedure closely resembled that of the Visual Patterns Test developed by Della Sala and colleagues (Della Sala et al., 1999) to measure visual working memory. Not surprisingly, the correlation between these two tasks and those chosen to represent working memory (Letter Rotation, Dot Matrix), both of which involved the maintenance and manipulation of visual images, was strong (r=.86). As there was a moderate correlation (r=.59) between the combined visuospatial variable and the executive function variable, they concluded that the visuospatial storage involved in the performance of the visuospatial tasks was dependent on central executive involvement or controlled attention. These results and those reported in the preceding paragraph provide further support for the close link between visuospatial working memory, central executive functioning, and attention, as discussed in section 4.5.

In summary, extensive investigations of working memory have provided substantial support for Baddeley's (1986, 2000, 2001) model. Whilst the role of the phonological loop has been widely accepted, debate about the visuospatial sketchpad is ongoing. Although unanimous agreement on the composition of the sketchpad has not occurred, the majority of research appears to support a visual-spatial dichotomy. There is also neuroimaging and behavioural evidence suggesting that visuospatial processing is closely linked with some functions of the central executive. Whilst neuroimaging studies support the notion that working memory is one of many possible cognitive processes underlying executive functioning, its role in the performance of executive tasks is not uniform with some tasks showing a greater involvement of visuospatial working memory (Tower of London) and others verbal working memory (WCST). As tests of executive function are of primary importance in the assessment of a wide range of neurological, neuropsychological, and developmental conditions, determining the contribution of working memory to performance on these tasks could facilitate a better understanding of executive functions and could potentially be of benefit in developing rehabilitation programmes.

CHAPTER 5

Working Memory and the Wisconsin Card Sorting Test

It is generally accepted that working memory is necessary for performance of the Wisconsin Card Sorting Test (WCST). However, it has been suggested that "it is not likely to be sufficient for a successful performance" (Stratta et al., 1997, p.18). It has also been hypothesised that working memory and the executive functions underlying WCST performance may even be dissociable neurocognitive constructs (Stratta, Prosperini, Daneluzzo, Bustini, & Rossi, 2001). Conversely, reduced working memory capacity has been proposed to account for age-related decline on the WCST (Hartman, Bolton, & Fehnel, 2001) and perseveration, which is considered the primary indicator of impaired function, has been attributed to central executive and/or phonological loop impairment (Baddeley, 1996; Baddeley, Chincotta et al., 2001; Dunbar & Sussman, 1995). Research into the role of working memory in WCST performance, reviewed in this chapter, has provided inconsistent results. In particular, the contribution of the different components of the working memory model is ambiguous and warrants further investigation.

5.1 Neuroimaging studies

Neuroimaging studies investigating WCST performance have found *bilateral* activation in a number of cortical regions including the prefrontal (Brodmann areas 6, 9, 12, 46, 47), anterior cingulate (areas 24 and 32), parietal (areas 7 and 40), and prestriate cortices (area 19) as well as subcortical areas of the caudate nucleus, putamen, and thalamus (Monchi et al., 2001). Areas activated by working memory tasks, on the other hand, have shown hemispheric specificity depending on the type of task performed with verbal tasks activating *left* prefrontal (areas 6, 44, and 46) and parietal (area 40) regions, spatial tasks activating *right* prefrontal (areas 6, 46, and 47), prestriate (area 19), and parietal (area 40) regions and visual tasks activating *left* inferotemporal (area 37) and parietal (area 40) regions (Smith et al., 1996; Smith et al., 1995). Yet, with increased memory load activation has been seen bilaterally but with greater intensity in the respective key regions (Smith et al., 1996). These findings show a significant overlap in activation on performance of these tasks but the degree of contribution made by working memory toward successful WCST performance is not clear, particularly as there appear to be distinct mechanisms for verbal, visual, and spatial working memory. Whilst neuroimaging studies provide evidence for a link between the underlying neural bases of WCST and working memory (Konishi et al., 1999), behavioural studies involving clinical and nonclinical populations have endeavoured to clarify the contribution to WCST performance made by the different components of working memory. Although WCST performance per se has been investigated in a variety of clinical populations, as described in Chapter 3, specific examination of the relationship between working memory and WCST performance has occurred predominantly in schizophrenia research. Nonclinical samples have included young and older adults from universities and the wider population.

5.2 Research in nonclinical populations

Studies investigating age differences on WCST performance have cited impairment in cognitive flexibility, working memory, and processing speed as possible factors responsible for older adults' failure to use feedback information effectively. Fristoe and colleagues (1997) administered a range of computerised processing speed tasks, numerical and verbal working memory tasks, and two versions of the WCST (standard; with hypothesis generation) to 48 young adults (18-38 years) and 49 older adults (60-86 years). The modified version of the WCST required participants to indicate on what basis they intended to make their response prior to doing so to determine the proportion of trials for which participants changed their mind after feedback. Data were analysed using principal components, hierarchical regression, and path analyses. Although feedback usage and working memory were shown to be important factors in age related differences the results indicated that the primary mediator in performance was speed of processing. However, working memory was measured by verbal tasks only and it could be argued that the WCST measures chosen to represent performance (categories achieved, percentage of perseverative errors, percentage of conceptual level responses) were too few given that nonperseverative as well as perseverative errors affect the number of categories achieved and a loss-of-set/failure-to-maintain-set score has been considered indicative of working memory ability (Greve et al., 2002).

A reduction in cognitive flexibility has also frequently been cited as an explanation for age related decline in WCST performance. Hartman et al. (2001) conducted two well conceptualised experiments to determine whether age differences were due to increased inflexibility or diminished working memory capacity, and whether the ineffective use of feedback by older adults was due to a reduction in the ability to update working memory. As perseveration is indicative of cognitive inflexibility Hartman et al. examined the pattern of errors by distinguishing between perseverations to the immediately preceding category (previous-category perseverative errors) and perseverations to a different incorrect category (different-category perseverative errors). They hypothesised that if age related differences were caused by inflexibility then older adults should commit more perseverative than nonperseverative errors and that the increase should be in the previous-category type because of the amount of positive reinforcement given prior to a rule change. To evaluate the role of working memory capacity in WCST performance Hartman et al. examined the errors made under high and low processing and high and low memory load. An error was rated as high processing after an incorrect sort and low processing after a correct sort. As memory load was considered high when information from multiple previous sorts was needed to determine the correct rule, errors were rated as having high memory load following either a correct sort after an ambiguous card or an incorrect sort after an unambiguous card, and low memory load following either a correct sort after an unambiguous card or an incorrect sort after an ambiguous card. The results of the first experiment involving 85 young adults (mean age=19.7 years) and 75 older adults (mean age=70.3 years) revealed that contrary to the inflexibility hypothesis a similar proportion of perseverative and nonperseverative errors were made by both age groups. Older adults also made significantly more different-category than previous-category perseverations. Moreover, the results supported the hypothesis of reduced working memory capacity in accounting for age differences in performance as more errors occurred when processing and memory load were high for both age groups even if overall older adults made more errors than young adults.

Their second experiment involving 48 young adults (mean age=20.3 years) and 48 older adults (mean age=69.8 years) used visual cues to investigate the hypothesis that errors occur due to an inability to adequately update working memory. The visual cues consisted of arrows printed with 'yes' or 'no'. These were placed above the most recent sort to eliminate the need for storage of information under low memory load conditions and to reduce the amount of storage required under high memory load conditions. Half the participants in each age group were administered the original version of the WCST and half the version with the visual cues. The cued version eliminated all age differences and also improved the older adults performance to the level of the young adults on the original version. This suggests that without the aid of visual cues feedback information for older adults is not being adequately encoded and stored in working memory. As well as providing supportive evidence for working memory as an underlying cognitive process to WCST performance these results also highlight the importance of examining the quality and pattern of errors committed, particularly the inclusion of nonperseverative errors in investigating the role of working memory in WCST performance.

Whilst the aforementioned studies have provided important information about WCST performance and working memory capacity per se, others have attempted to discriminate between the contributions made by different components of working memory. So far, only two components, the central executive and phonological loop, have been considered. Doiseau and

Isingrini (2005) factor analysed data from an updating working memory task administered to older adults (mean age=77.9 years) and subsequently investigated the relationship between the central executive and the WCST after extracting two factors on the working memory task. Factor 1 was interpreted as reflecting the phonological loop and Factor 2 the central executive. A correlational matrix indicated that only Factor 2, reflecting the central executive, was significantly correlated with the WCST measures of categories achieved, total errors, and perseverative errors. The results, however, require cautious interpretation as only 50 participants were involved in the factor analysis, which is considerably smaller than the 150-300 recommended by Tabachnick and Fidell (1996).

Dunbar and Sussman (1995) conducted a series of five experiments to investigate the memory mechanisms underlying perseveration on WCST. For the first two experiments they used a dual-task paradigm to examine the phonological loop and central executive and concluded from their findings that perseveration was due to a deficit in the phonological loop rather than the central executive. However, it is debatable as to whether the secondary tasks used suitably reflected the respective working memory components. In the first experiment participants were given a secondary task which required them to either orally repeat digits presented every 3 sec and then recall all digits presented at the sound of a tone (phonological condition) or add sequentially a series of presented digits and state the total at the sound of the tone (executive condition). Although more perseverative than nonperseverative errors were made in the phonological condition the researchers conceded that the secondary tasks may not have solely tapped the targeted components and used different tasks in the second experiment. In this experiment they used articulatory suppression, a well supported secondary task for the phonological loop, but for the executive condition they used a tone detection task that required participants to press a foot pedal when they heard a randomly presented tone. Although the authors considered the tone detection task a purer version of a central executive task it involved neither a memory load nor a requirement for manipulation and could alternatively be considered a sustained attention task similar to the continuous performance task. The results from this second experiment showed no significant difference between the three groups (control, phonological, executive) in categories achieved, number of perseverative errors, and nonperseverative errors. However, the authors concluded that as more perseverative errors were made in the second category in the phonological condition that this was consistent with the hypothesis that perseveration is due to a deficit in the phonological loop. Apart from the secondary tasks used, the between subjects design and small sample sizes of 12 (exp 1) and 11 (exp 2) university undergraduates in each group lead to reservations about the conclusions drawn.

Cinan and Tanör (2002) also investigated the role of the phonological loop and central executive in WCST performance and additionally explored the visual aspects of the task in relation to the function of response inhibition. The secondary tasks of articulatory suppression (phonological loop) and random letter generation (central executive) were combined with three modified versions of the WCST to create five groups each consisting of 15 university students. In the three WCST versions all 128 cards were sorted and participants were told each time the sorting rule changed as well as being informed of the new rule to be used. The dependent measures were stimulus-response errors, which occurred when the response card was incorrectly matched against a key card, and response-response errors, which occurred when a response card was matched according to the previous incorrect response card. In the WCST-4 version participants were asked to sort the response cards to the standard key cards by the specified rule under three conditions; one group performed the task alone, one group concurrently with articulatory suppression, and one group concurrently with random letter generation. In the WCST-12 version the key cards were uni-dimensional, that is, there were three rows of four cards (one row of colours, one row of colourless shapes, one row of written numbers) and each row was presented as the key cards according to the specified sorting rule. The fourth group performed this version concurrently with random letter generation. The third version, WCST-12-box, followed the same format as the WCST-12, except that the response cards were posted in individual boxes so that, unlike the other versions, the previous response cards could not be seen, that is, there was no visual feedback. The results showed no effect of articulatory suppression on performance of WCST-4, which the authors interpreted as supporting the involvement of the phonological loop in the original WCST. They reasoned that in line with Dunbar and Sussman's (1995) view, disclosing the sorting criteria at each sort eliminated the need for phonological working memory. A significant effect of random letter generation, however, was found with significantly more stimulus-response errors occurring when the three dimensional cards were used (WCST-4) and significantly more response-response errors occurring in the conditions under which the response cards remained in view (i.e., with visual feedback). Few errors occurred in the box (i.e., no visual feedback) condition. Cinan and Tanör are the only researchers who have investigated the visual aspects of the WCST, albeit to a limited extent. Although they interpreted the results as demonstrating response inhibition as a function of the central executive, investigating the role of the visuospatial sketchpad and phonological loop within the same study could provide an alternative explanation with respect to visual feedback. The use of non-standard dependent measures also makes it difficult to compare the results with those of other studies.

5.3 Schizophrenia research

Schizophrenia is associated with impairment in a broad range of cognitive functions. This impairment appears to be present in most patients irrespective of the severity of their symptomatology (Fucetola et al., 2000; Gur, Ragland, & Gur, 1997). As reduced working memory ability has been postulated to mediate these deficits (Goldman-Rakic, 1994) and significant WCST impairment has been found in patients across the schizophrenia spectrum, a number of studies have investigated the relationship between working memory and WCST performance involving patients with schizophrenia, schizoaffective disorder, schizotypal personality disorder, and with individuals psychometrically identified as having schizotypal traits (schizotypy). Although the findings from research examining specific cognitive processes in a schizophrenia population are complicated by the many confounding variables, they have nevertheless provided valuable information.

5.3.1 *Working memory-WCST performance in schizophrenia patients.* As in nonclinical populations some studies have investigated working memory capacity rather than the contribution of specific components to WCST performance. Hartman et al. (2003) conducted a study with 28 schizophrenia patients and 28 controls using the same procedure as in the previously described study with older adults (Hartman et al., 2001). That is, defining errors according to both high and low processing load and high and low memory load plus a modified WCST version using arrows printed with 'yes' or 'no' as visual cues to previous responses. In this study they also included a delayed matching to sample task as a measure of speed of encoding into working memory. As expected patients with schizophrenia made significantly more errors than controls in both the standard and modified versions of WCST, but more errors were made by all participants when memory and processing loads were high, again providing support for the role of working memory in WCST performance. However, a practice effect was noted on the second WCST administration. On the modified version this effect was stronger for memory than processing load, which suggests that the visual cues reduced storage demands without benefiting processing demands. Another interesting result of the practice effect was that although the total number of errors was reduced, the reduction occurred in perseverative errors only, with the number of nonperseverative errors remaining unchanged. Similar results were found in a study with 16 patients with schizophrenia (Everett, Lavoie, Gagnon, & Gosselin, 2001) who were readministered the WCST after being told of the sorting principles and who were provided with instructions and verbal reinforcement throughout the test. It would therefore seem that when support is provided the tendency to perseverate is reduced but that the underlying working memory deficit, the inability to maintain and manipulate information, remains.

Correlational results in the Hartman et al. (2001) study between the delayed matching to sample task and the number of categories achieved ($r=-0.54$, $p<.01$) and the total number of errors ($r=0.58$, $p<001$) plus the results of analyses using the delayed matching to sample task as a covariate indicated that impaired performance on the WCST was related to slower encoding into working memory. This corresponds to the findings of other studies, in which a deficit in updating working memory has also been proposed to account for poor WCST performance (Fristoe et al., 1997; Hartman et al., 2001).

Whilst not directly addressing the issue of working memory, Perry, Potterat, and Braff (2001) found that when patients with schizophrenia were asked to verbalise their strategies with each card sort, the number of perseverative errors were significantly less than under standard conditions. However, this only occurred for the group (n=36) who were instructed to verbalise on the first WCST administration followed by the standard version whereas there was no such improvement for the group (n=37) who were first administered the standard version. The authors suggested cognitive inflexibility as an explanation for these results in that once patients have established an incorrect cognitive schema they are unable to benefit from additional strategies. Nonperseverative errors were not recorded in this study. Nevertheless, these results taken with those of the aforementioned studies suggest that the number of perseverative errors made may reflect the extent of cognitive inflexibility whereas nonperseverative errors maybe more a reflection of working memory ability and should be included more often in studies examining the role of working memory in WCST performance.

Auditory and visual working memory have been found to be impaired in patients with schizophrenia which has resulted in a variety of working memory tasks being used in studies investigating the working memory-WCST link. Gold et al. (1997) assessed the performance of 36 patients with schizophrenia and 30 controls on a neuropsychological battery. Included were the WCST and Letter-Number Span, an auditory working memory task that requires the storage (phonological loop) and manipulation (central executive) of information. A stepwise regression analysis of the WCST category score indicated that with the exception of the percent perseverative error score the most significant predictor was Letter-Number Span, which accounted for 54% of the variance in performance. Conversely, an analysis of the percent perseverative error score did not include Letter-Number Span as a predictor, with the Trail Making Test and verbal fluency being the two most significant predictors. As suggested by the researchers, working memory capacity may only be a predictor to a certain threshold after which other cognitive variables (e.g., inhibitory control, cognitive inflexibility) become the primary predictors of perseveration. In contrast, Glahn et al. (2000) found that when they covaried a visual reasoning plus working memory task with the categories achieved and perseverative error scores the group differences between the patients with schizophrenia (n=62) and controls (n=62) became non-significant for both scores. Although the working memory task used could be considered visual as it consisted of coloured shapes presented on a computer screen, the shapes could be verbalised plus patients' scores on this task were significantly correlated with digit span. This suggests that the task was also a verbal working memory task employing the phonological loop.

Another suggestion of phonological loop involvement in WCST performance was provided by Grön (1998) in his study involving patients with frontal lobe damage (n=6), nonfrontal lobe damage (n=6), schizophrenia with impaired WCST performance (n=6), schizophrenia without impaired WCST performance (n=6), and controls (n=6). Using modified Sternberg tasks with letters, nonsense geometrical figures (visual) and nonsense syllables (auditory) he found that patients with frontal lobe lesions were impaired on performance of both the visual and auditory tasks, which he attributed to an impaired central executive. In contrast, schizophrenia patients with impaired WCST performance only showed impairment on the auditory task. The schizophrenia patients also had the lowest digit span scores compared to all other groups. Grön concluded that although a deficit in the phonological loop was a possible explanation for poor WCST performance, poor performance could also reflect a dysfunction in the interaction between the central executive and cortical areas constituting the loop. Furthermore, even though a visual working memory task was included, a ceiling effect in the schizophrenia group meant that an impaired visuospatial sketchpad could not be discounted.

Researchers who have included visuospatial working memory tasks in their studies have offered varying interpretations of their results. Gooding and Tallent (2002) compared patients with schizophrenia (n=34), patients with schizoaffective disorder (n=23), and community controls (n=30) on performance of the WCST, a computerised spatial working memory task, and a sensorimotor control task. The delayed-response task has been used in several studies as a measure of spatial working memory. On a computer screen an 'X' is randomly displayed for 200 ms in one of eight spatial locations, followed by a 10 s delay period in which participants complete a distractor task to prevent rehearsal. After the delay eight reference squares or circles appear and participants are required to indicate the prior location of the target 'X'. In this study the WCST was scored in terms of categories achieved, number and percentage of perseverative errors, number of nonperseverative errors, trials to complete first category, conceptual level responses, and failure to maintain set. Nonparametric statistics were used for all analyses which revealed that the patients' scores were significantly poorer than for the controls on the working memory task ($p<.001$) and on all WCST measures ($p<.001$), except failure to maintain set. However, there was no group difference on the overall accuracy of the sensorimotor task. For both schizophrenia and schizoaffective patients Spearman's rank order correlation revealed a significant positive association between the percent correct on the working memory task and categories achieved (r_s=0.41 & 0.46 respectively, *p*s<.05) and a negative association between the working memory task and the number of perseverative errors (r_s=-0.45 & -0.52 respectively, *p*s<.05). No significant association was found between the working memory task and the number of nonperseverative errors. These results suggest that spatial working memory contributes to successful WCST performance. It is also interesting to note that in these patient groups who have a high level of cognitive impairment that there was no difference between groups on the failure to maintain set score. This is in line with Greve et al.'s (2002) proposal of a hierarchical structure in which the lower levels of an ability to shift set and problem-solve need to be intact before an increase in failure to maintain set score is disclosed.

In contrast, contrary results were found by Stratta et al. (2001) who conducted an experiment with 25 schizophrenia patients and 35 age-matched controls using the same tasks as Gooding and Tallent (2002) except that WCST performance was only based on the number of categories achieved, total errors, and perseverative errors. No significant correlation was found between the working memory task and WCST indices for either group. Although performance was significantly poorer for the patients with schizophrenia on all WCST measures the group differences were no longer significant when educational level was used as a covariate. However, a significant difference remained for the working memory task with educational level as a covariate, with the percent correct scores for the schizophrenia patients being lower than for the controls. The authors acknowledged that using educational level instead of either premorbid IQ, parents' educational level, or scores on the Wide Range Achievement Test as a covariate might have biased patients' premorbid estimate. Nevertheless, they concluded that the lack of correlation between the working memory task and WCST measures suggests that working memory and executive functions are different and dissociable neurocognitive constructs.

One major difference between the Stratta et al. (2001) and Gooding and Tallent (2002) studies is the method of analysis. Whereas Gooding and Tallent used nonparametric statistics due to the violation of the assumption of homogeneity of variance, Stratta et al. employed Pearson's correlations and multivariate analyses of variance. As the group characteristics and sample sizes were similar the assumption of homogeneity of variance in the Stratta et al. study could be questioned and may have impacted on the results.

In a previous study of 30 schizophrenia patients and 25 age, sex, and educational matched controls Stratta et al. (1997) also found no significant correlation between any working memory measure and the WCST indices. Digit Span (forwards and backwards) was used as a measure of verbal working memory. As a measure of visuospatial working memory the authors devised a memory card game using 12 identical pairs of the WCST cards with the aim being to find the card pairs in the least number of trials. The authors considered the visuospatial task as complex, sensitive in detecting impairment, and close to a working memory function in WCST performance. However, it could be argued that unless subvocal rehearsal was prevented, the WCST cards and their location could easily be verbalised such that the task could not be considered a pure visuospatial task. Some of the correlational results in this study are also problematic. Although significant negative correlations were found for the control group between categories achieved and perseverative errors (r=-0.63, p<.001) and between categories achieved and total errors (r=-0.75, p<.001), for the schizophrenia patients a significant positive correlation between categories achieved and total errors (r=0.42, p<.05) was reported; although this may be a typographical error. Furthermore, there was no significant correlation between digits forwards and backwards (r=0.36) in the control group. This is inconsistent with previous findings that have found these tasks to be highly correlated (r=.57, p<.001) in a nonclinical

5.3.2 *Working memory-WCST performance in a schizotypic population.* Within the schizotypic research healthy individuals, mostly university undergraduates, have been assessed for schizotypic traits according to one of two self reported screening instruments; the four subscales of the Chapman Psychosis-Proneness Scales (Perceptual Aberration, Magical Ideation, Social Anhedonia, Physical Anhedonia) and the Schizotypal Personality Questionnaire (SPQ) or Schizotypal Personality Questionnaire-Brief (SPQ-B). The Perceptual Aberration Subscale, which has been used in isolation to assess schizotypy in some studies, has shown good test-retest reliability (0.75) but weak criterion validity (Chapman, Chapman, & Miller, 1982). The SPQ has been shown to have high internal reliability (0.91), test-retest reliability (0.82), convergent validity (0.59 to 0.81), discriminant validity (0.63), and criterion validity (0.68) with similar correlations for the SPQ-B (Raine, 1991; Raine & Benishay, 1995). Though the subscales of the Chapman Psychosis-Proneness Scales measure individual features of schizotypal personality, the SPQ and SPQ-B assess all nine features of schizotypal personality disorder as defined by the DSM-III-R (American Psychiatric Association, 1987). Evidence for a relationship between schizotypy and WCST performance and schizotypy and working memory has been provided by studies using both measures to classify schizotypy.

Lenzenweger and colleagues (Lenzenweger & Gold, 2000; Lenzenweger & Korfine, 1994; Park et al., 1995) used the Perceptual Aberration Subscale to classify university undergraduates in their studies investigating the WCST and auditory and spatial working memory. Scores 2 SD above the group mean were rated as schizotypic, whereas controls were required to score no higher than 0.5 SD above the group mean. Nonetheless, their results were not consistent across the studies. In one study (Lenzenweger & Korfine, 1994) the results indicated that schizotypic participants (n=23) had a tendency to complete fewer categories ($p<.08$), required more trials to complete the first category ($p<.09$), and failed to maintain set significantly more often ($p<.05$) than controls (n=28). In contrast Park et al. only found a significant difference in the failure to maintain set score ($t(49)=1.99$, $p<.05$) with no significant difference between schizotypic participants (n=28) and controls (n=23) on number of categories achieved, perseverative errors, trials to first category, or learning to learn. They did, however, find a significant difference on the spatial working memory task (delayed response task) with performance of the schizotypic participants less accurate than controls ($t(49)=1.79$, $p<.05$). A significant negative correlation between the working memory task and failure to maintain set score ($r=-.34$, $p<.01$) seems to suggest that individuals with a high level of schizotypic traits have difficulty in maintaining spatial representation in working memory. These results with a spatial working memory task were not replicated with an auditory task (Letter-Number Span) with both schizotypic participants (n=31) and controls (n=26) performing identically on both the total number of correct responses and the longest string achieved (Lenzenweger & Gold, 2000). As the same participants were involved in both studies the researchers conducted a correlational analysis between the auditory working memory scores and WCST scores but no significant correlation was found for any measure. Taken together, these findings appear to indicate that there is a relationship between spatial but not auditory working memory and successful WCST performance.

However, the use of only one subscale from the Chapman Psychosis-Proneness Scales may not have been sensitive enough in detecting all schizotypic traits.

Tallent and colleagues (Gooding, Kwapil, & Tallent, 1999; Tallent & Gooding, 1999) rated university undergraduates for schizotypal traits using the Perceptual Aberration, Magical Ideation, and Social Anhedonia subscales. A computerised version of the WCST was administered with standard instructions and nonparametric statistics were used in both studies. In these studies schizotypic participants (n=115 and n=155 in the respective studies) achieved significantly fewer categories, more perseverative errors, and a higher rate of failure to maintain set scores than controls (n=63 and n=104). In the Tallent and Gooding study, working memory was assessed using the spatial delayed response task described earlier. For the entire sample only 6% achieved less than 93% correct on the working memory task. Nevertheless, there was a significant inverse relationship between accuracy on the working memory task and the number of perseverative errors (r_s=-0.17, p<.05) and trials to complete first category (r_s=-0.15, p<.05) although a lack of variability in performance may have influenced the correlations. No other associations between the working memory task and WCST indices, including failure to maintain set score, were significant. For the entire sample participants scoring in the bottom 5th percentile on the working memory task also had a significantly higher percentage of perseverative errors than those in the top 5th percentile. Whilst there appears to be a relationship between spatial working memory, schizotypy, and WCST performance the authors conceded that the working memory task used might not have been specific or sensitive enough for an undergraduate population.

The following studies used the Schizotypal Personality Questionnaire (SPQ) to evaluate schizotypic traits. In a group of patients with schizophrenia and a group of undergraduate and postgraduate students Daneluzzo, Bustini, Stratta, Casacchia, and Rossi (1998) found a significant correlation between total SPQ scores and categories achieved (r=-0.32, p<.05), percent perseverative errors (r=0.39, p<.01), and learning to learn (r=-0.60, p<.01) in the student group. When Park and McTigue (1997) examined spatial working memory (delayed response task) in an undergraduate population (n=89) in relation to schizotypy their results revealed no significant correlation between the total SPQ and working memory scores. However, when they divided participants into a designated schizotypal group (SPQ scores above 90th percentile; n=14) and a control group (SPQ scores below 90th percentile; n=75) they found that the schizotypal group had made significantly more errors on the working memory task than the controls (F(1,87)=3.7, p<.05). As in previous studies accuracy was high (96.9%) on the delayed response task, which again suggests that this task may not be a sensitive measure for a high functioning university population and may account for the nonsignificant correlation between SPQ and working memory scores.

In an event-related potential study Kopp, Wolfe, Hruska, and Reischies (2002) assessed a group of psychometrically identified schizotypic individuals on an associative learning task. Their results revealed an attenuated amplitude of the occipito-temporal N150 component for the schizotypic participants which they interpreted as indicating a deficiency in being able to encode visual stimuli in working memory involving either the central executive or episodic buffer.

In summary, the majority of studies provide empirical support for a significant contribution of working memory to WCST performance. Neuroimaging studies indicate overlapping areas of activation for WCST performance and working memory, with distinct neural mechanisms for verbal, visual, and spatial working memory tasks. Research involving nonclinical populations has provided substantial support for the importance of working memory to successful WCST performance although processing speed has also been proposed as mediating working memory. Within these studies deficits in the central executive and phonological loop have both been proposed as an explanation for poor performance though methodological anomalies make definitive conclusions difficult. Whilst visuospatial working memory has not been investigated in the nonclinical research, auditory and spatial tasks have both been used in studies involving patients with schizophrenia and psychometrically identified individuals with schizotypal personality traits. As working memory is one of many cognitive processes impaired in schizophrenia conclusions regarding the WCST-working memory link have mainly been inferred from correlational and regression analyses. These have provided consistent support for phonological loop involvement but no consensus has been reached with regards to spatial working memory. In the schizotypic research participants rated high on schizotypic traits have been found to make more errors on spatial working memory tasks and to achieve fewer categories, more perseverative errors, and more failure to maintain set scores on the WCST than low schizotypic participants. Whilst no significant correlations have been found between auditory working memory and WCST scores, some studies have found significant correlations between spatial working memory and some WCST scores although the results have not been consistent. Some of the problems identified in the preceding studies include questionable secondary tasks, small sample sizes, the appropriateness of nonparametric versus parametric statistics for analysis, and the lack of sensitivity of the spatial task used in the schizotypic studies. Highlighted in those studies that reported perseverative and nonperseverative errors as well as the failure to maintain set score, is the importance of examining the quality of errors when investigating the relationship between working memory and WCST performance. Although working memory involvement in WCST performance has been established, the degree to which involvement translates to successful performance and the relationship between the specific components of working memory and the WCST index scores has not been clarified, warranting further investigation.

CHAPTER 6

Experiment 1A: Card Sorting, Working Memory, and Schizotypy

The aim of the series of experiments described in this thesis was to clarify the extent to which successful WCST performance is dependent on working memory and to determine the relationship between the different components of the working memory model and WCST index scores. Additionally, it aimed to provide a link between the findings in a nonclinical population to those in a clinical population, specifically individuals with mild to moderate closed head injury.

As reviewed in Chapter 5, studies investigating the role of working memory in WCST performance have primarily used tasks considered to be verbal (digit span, letter-number span, articulatory suppression) or spatial (delayed response task), or tasks that have been shown to interfere with the central executive (letter-number generation; alternating letters and numbers). Researchers have variably attributed a decrease in WCST categories achieved or increase in perseverative errors to a deficit in either the phonological loop (Dunbar & Sussman, 1995; Gold et al., 1997) or the central executive (Doiseau & Isingrini, 2005). In the schizophrenia research correlational analyses have indicated significant correlations between an auditory working memory task (Letter Number Span) and categories achieved (Gold et al., 1997); a spatial working memory task (delayed response task), categories achieved and number of perseverative errors (Gooding & Tallent, 2002) or conversely no significant correlations between working memory tasks and any WCST index (Stratta et al., 1997; Stratta et al., 2001). Although involvement of the visuospatial sketchpad has been suggested, few studies have directly investigated its relationship to WCST performance. Of those, most have used a spatial working memory task. In one study in which a visual task was used a ceiling effect may have compromised the results (Grön, 1998) and in another study (Stratta et al., 1997) verbal strategies could have been used which would have involved the phonological loop. No identified study has investigated all components of working memory within the one experiment.

Another aspect of WCST performance, which has yet to be fully investigated, is the effect of visual feedback. During the administration of the original (Milner, 1963) and Nelson's (1976) version of the WCST, previous response cards remain in view (visual feedback from previous sorts). However, many modified versions used in researching the cognitive processes underlying WCST performance appear to have inadvertently omitted visual feedback; once a key card has been selected the target card changes without the previous card remaining in view. Cinan and Tanör (2002) investigated the visual aspects of the WCST with respect to response inhibition and found that significantly fewer errors were made when there was no visual feedback. As they did not use the standardised scoring procedure it is difficult to determine whether the presence or absence of visual feedback significantly alters the contribution of the different components of working memory and therefore the index scores.

Performance on the WCST is measured by multiple indices. Although nine index scores can be derived (see p.22), the number of categories achieved, total number of errors, and number of perseverative errors are the most widely accepted as reflecting impaired performance. Within the research literature, however, some studies have shown that whilst perseverative and nonperseverative errors both contribute to the categories achieved score, a high perseverative error score may be due to cognitive inflexibility whereas a high nonperseverative error score may reflect impaired working memory (Everett et al., 2001; Hartman et al., 2001; Hartman et al., 2003; Perry et al., 2001). Furthermore, a nonperseverative error score as defined in the original WCST consists of errors made using an appropriate trial and error strategy as well as errors due to an inability to maintain set. According to Barceló and Knight (2002), who defined these errors as efficient errors and random errors respectively, the conventional scoring of nonperseverative errors does not discriminate between an appropriate and an inappropriate strategy such that an indicator of impaired functioning may be overlooked. As demonstrated in their study with prefrontal patients and age-matched controls, significant differences between the groups for efficient and random errors disappeared when the errors were combined and analysed as nonperseverative errors. The importance of investigating the quality of errors in association with working memory was also highlighted by studies that found a reduction in perseverative errors but not nonperseverative errors when visual or verbal cues were used during WCST administration (Everett et al., 2001; Hartman et al., 2003).

In this first experiment Barceló's (1999, 2001; Barceló & Knight, 2002) Madrid Card Sorting Test (MCST) was used in conjunction with the WCST to investigate the quality of errors and visual aspects of card sorting test performance. The MCST was designed to assess attentional set shifting rather than concept formation or problem solving. Twenty-four unambiguous cards are used repeatedly to produce 18 predetermined categories for a total of 137 trials. The length of each category varies between six and nine trials so that participants are unable to anticipate the start of a new sorting rule. Prior to commencement of the test, participants are informed of the three sorting rules (colour, number, shape) and that the sorting rule will change without warning. Correct and incorrect feedback after each response is given as per the WCST. Nelson's (1976) definition of a perseverative error (see p.25) is used and nonperseverative errors are classified as either efficient or random errors. An efficient error is defined as an incorrect response in the second trial only of each category, which is different from the immediately preceding response, indicating an appropriate trial and error strategy. A random error is defined as an incorrect response that is different from the immediately preceding response.

The aims of Experiment 1A were:

a) to determine the comparability of performance on the standard WCST (Heaton, 1981) in which visual feedback is present and the Madrid Card Sorting Test (MCST: Barceló, 1999, 2001) in which visual feedback is absent.

b) to examine the relationship between the components of Baddeley's working memory model and the WCST index scores.

University students psychometrically identified as having schizotypal personality traits were chosen to participate. Individuals with high schizotypic scores have been found to display a profile of psychological, social, and cognitive features similar, though attenuated, to those observed in individuals with schizophrenia but without the confounding variables of medication and illness symptomatology.

The working memory tasks used in the present experiment are well recognised and have been used extensively in the working memory research (see Chapter 4). Two tasks were chosen to represent each modality. Digit Span and Letter-Number Span are reliant on the phonological loop and central executive, as they require the maintenance and storage of auditory material. Spatial Span, which is the Wechsler Memory Scale version of the Corsi Blocks, and the Spatial Delayed Response Task involve the visuospatial sketchpad and require the maintenance and rehearsal of spatial information. The Visual Patterns Test was developed and has been supported as a specific measure of visual working memory (see section 4.5). The procedure for the Coughlan Design Learning Test is similar and the presentation of one trial is considered an appropriate measure of working memory. This test consists of 16 dots in a 4 x 4 configuration in which nine lines form a pattern joining the dots. The line pattern is presented for 10 s after which time participants are given a 4 x 4 dot configuration and are required to recall the line pattern. Although the processes of the visual and spatial tasks overlap, previous research has provided support for the separate contribution of the visual and spatial components of the visuospatial sketchpad, respectively (Della Sala et al., 1999).

It was hypothesised that participants with high schizotypic scores would make significantly more errors on working memory tasks and display poorer performance on the card sorting tests than participants with low schizotypic scores. In line with Hartman et al.'s (2001, 2003) findings, reviewed in section 5.2, in which a higher nonperseverative than perseverative score was related to working memory, a working memory hypothesis would suggest that if poor performance is due to a reduction in working memory capacity then high schizotypic scorers would achieve fewer categories and make more total errors than low schizotypic scorers but that the number of nonperseverative errors would be equal to or greater than the number of perseverative errors. However, if poor performance is not due to a reduction in working memory capacity then high schizotypic scorers would be expected to make more perseverative errors than low schizotypic scorers with no group difference on the number of nonperseverative errors. As a nonperseverative error score and a loss of set/failure to maintain set score are considered indicators of working memory ability a significant correlation between these and all working memory measures was predicted.

Method

Participants

Psychology 1 undergraduates (n=490) in two consecutive years at the University of Tasmania voluntarily completed a 44-item questionnaire that included the 22-item Schizotypal Personality Questionnaire-Brief (SPQ-B: Raine & Benishay, 1995) and 22 neutral filler questions (including validity questions) selected from the Eysenck Personality Questionnaire (1980) (Appendix A). Respondents who scored in the top and bottom 25% on the SPQ-B (high = $\geq$12, low = $\leq$5) and were in the 18 –35 age range were invited to participate in the study. Volunteers with a history of drug or alcohol abuse, neuropsychological or psychological problems, or who were colour-blind were excluded.

The final sample consisted of 45 high scorers on SPQ-B (m=13, f=32) and 45 low scorers (m=9, f=36). The study was approved by the Southern Tasmania Social Sciences Human Research Ethics Committee and written informed consent was obtained from all participants (Appendix A).

Materials

Intellectual ability was assessed by the National Adult Reading Test (NART: Nelson & Willison, 1991) with the Vocabulary subtest of WAIS-R (Wechsler, 1981) used as an alternative in the presence of a learning disability. The latter has been identified as an appropriate substitute for assessing intellectual ability (Crawford, Parker, & Besson, 1988).

Executive function was assessed by computerised versions of the Wisconsin Card Sorting Test (WCST: Heaton, 1999) and the Madrid Card Sorting Test (MCST: Barceló & Knight, 2002).

Auditory working memory was assessed by the Digit Span and Letter-Number Span subtests of WAIS-III (Wechsler, 1997a).

Visual working memory was assessed by the Visual Patterns Test (Della Sala et al., 1999) and the Coughlan Design Learning Test (Coughlan & Hollows, 1985).

Spatial working memory was assessed by the Spatial Span subtest of WMS-III (Wechsler, 1997b) and a computerised version of the Spatial Delayed Response Task (Gooding & Tallent, 2002)

Procedure

The tests were administered individually over two sessions of 30-60 min duration. In session 1 participants completed the NART and the WCST followed by three working memory tasks, one from each modality. In session

2 participants completed the MCST followed by the remaining three working memory tasks. The order of presentation of the working memory tasks was counterbalanced across and within each session.

Design and Data Analysis

A 2 [group: high scorers, low scorers] x 2 (card sorting test: Wisconsin, Madrid) x 6 (working memory tasks) mixed factorial design was used with group as the between subjects factor, and card sorting test and working memory tasks as the within-subjects factors. The dependent variables were scores on the working memory tasks; for WCST the number of categories achieved, the number of perseverative and nonperseverative errors, and the number of failure to maintain set; and for MCST the number of efficient, random, nonperseverative, and perseverative errors.

A multivariate analysis of variance was used to analyse between-schizotypal group data. One-way analyses of variance were used to analyse between-working memory group data. Pearson's product moment correlations were performed for all variables. An alpha level of .05 was used for all analyses.

Results

A between-subjects MANOVA was performed on 17 dependent variables: FSIQ; Wisconsin number of categories achieved, perseverative errors, nonperseverative errors, and failure-to-maintain set; Madrid number of efficient errors, random errors, nonperseverative errors, and perseverative errors; Digit Span Backwards-string length; Letter-Number Span; Visual Patterns Test; Coughlan Design Learning; Spatial Delayed Response Task; Spatial Span Forward, Backward and Total. The independent variable was schizotypal score (high; low). As no significant difference between schizotypal groups was found on the combined DV, Pillai's trace=.215, $F(16,73)=1.24$, and there was no significant correlation between schizotypic scores and other variables (Table 6.1), no further analyses on the personality variable were conducted.

As can be seen in Table 6.1, significant correlations were found between measures on the WCST and MCST and with the working memory measures. Although some variables did not reach the accepted .01 level of significance, those reaching significance at the .05 level are nevertheless of interest in inferring a different pattern of relationship between working memory and the two card-sorting tests. The Wisconsin indices showed no significant correlations with the auditory working memory tasks and perseverative errors were only significantly correlated with the spatial tasks. In contrast, Madrid random and nonperseverative errors were significantly correlated with the visual and spatial tasks and also showed a trend towards significance, as did the perseverative errors, with the auditory tasks. The Wisconsin failure to maintain set score was not significantly correlated with any working memory measure and the Coughlan Design Learning task was not significantly correlated with any card sorting test measure.

Further analyses on the data were performed by comparing the top and bottom 15% of scores on all working memory tasks with measures on the Wisconsin and Madrid Card Sorting Tests. A cut-off point of 15% was chosen in order to compare extreme scores while still preserving a viable sample size. As scores on the Coughlan Design Learning were not significantly correlated with any measure of the card sorting tests it was omitted from further

Table 6.1
Correlations between schizotypic scores, card sorting test indices, and working memory tasks.

	FSIQ	WCAT	WPE	WNPE	WFMS	MEE	MRE	MNPE	MPE	DSB	LNS	VPT	CDL	SDRT	SSF	SSB	SST
Schizotypy	.05	.11	-.16	-.06	.17	.09	.05	.07	-.05	.04	.07	-.01	-.04	-.08	-.14	-.08	-.13
Full Scale IQ (FSIQ)	_	-.02	-.05	-.12	-.01	.06	-.06	-.01	-.01	.21*	.35*	.07	.07	.09	.07	.12	.11
Wisconsin Categories (WCAT)		_	-.74**	-.44**	-.05	.14	-.42**	-.30**	-.52**	.05	-.03	.14	-.01	-.01	.18	.07	.15
Wisconsin Perseverative Errors (WPE)			_	.71**	.14	-.10	.40**	.31**	.55**	-.18	-.07	-.20	-.06	-.31**	-.22*	-.31**	-.30**
Wisconsin NonPerseverative Errors (WNPE)				_	.20*	-.01	.23*	.22*	.29**	-.11	-.02	-.18	.01	-.25*	-.09	-.26*	-.20
Wisconsin Failure to Maintain Set (WFMS)					_	-.03	.13	.11	.14	.03	.02	.08	.11	-.05	.11	-.19	-.02
Madrid Efficient Errors (MEE)						_	-.15	.36**	-.28**	-.08	.02	.01	-.03	.01	.01	-.01	.01
Madrid Random Errors (MRE)							_	.82**	.76**	-.23*	-.26*	-.29**	-.06	-.18	-.22*	-.31**	-.31**
Madrid NonPerseverative Errors (MNPE)								_	.54**	-.23*	-.21*	-.28**	-.10	-.14	-.20	-.27**	-.27**
Madrid Perseverative Errors (MPE)									_	-.21*	-.20	-.26*	-.07	-.16	-.14	-.17	-.18
Digit Span Backwards (DSB)										_	.39**	.12	.17	.14	.29**	.40**	.40**
Letter Number Span (LNS)											_	.27**	.28**	.15	.16	.34**	.29**
Visual Patterns Test (VPT)												_	.52**	.16	.42**	.36**	.46**
Coughlan Design Learning (CDL)													_	-.05	.28**	.21*	.30**
Spatial Delayed Response Task (SDRT)														_	.11	.22*	.19
Spatial Span Forward (SSF)															_	.43**	.87**
Spatial Span Backwards (SSB)																_	.81**
Spatial Span Total (SST)																	-

*$p<.05$, **$p<.01$

analyses. The number of participants in each group for each working memory task is shown in Table 6.2.

Table 6.2

Number of participants in the top (high) and bottom (low) 15% for each working memory task.

	DSB	LNS	VPT	SDRT	SSF	SSB	SST
High	18	22	18	28	17	15	19
Low	25	17	16	13	21	25	17

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Percentage of total errors

The number of trials completed on the WCST varied, so total errors were calculated as a percentage to enable comparison. Separate 2 [group: high scorers, low scorers] x 2 (card sorting test: Wisconsin, Madrid) ANOVAs were performed on all working memory tasks with the between-subjects factor being group and the within-subjects factor being card-sorting test. As Levene's Test of Equality indicated a violation of the assumption of homogeneity for one or more variables, skewness and kurtosis were assessed (Appendix A). Consequently, logarithm transformations, which produced the best fit, were used for all ANOVAs. In the following tables (Tables 6.3-6.6) the F-values for the transformed variables are reported.

For the percent of total errors, significant main effects for card-sorting test were found on all working memory tasks indicating that a significantly

higher percentage of errors occurred on the MCST than on the WCST (Table 6.3). A significant main effect for group was found for Spatial Span

Table 6.3

Mean percent of total errors (standard deviations) on the WCST and MCST for each working memory task using logarithm transformed variables.

	DSB***	LNS***	VPT**	SDRT**	SSF**	SSB***	SST**
F value	(1,41)=29.46	(1,37)=30.10	(1,32)=10.27	(1,39)=13.86	(1,36)=12.10	(1,38)=17.44	(1,34)=12.02
WCST	8.45 (7.02)	7.74 (6.21)	9.38 (8.14)	9.00 (6.50)	10.32 (9.05)	8.55 (7.18)	10.09 (9.36)
MCST	14.00 (8.89)	14.18 (9.18)	12.65 (8.61)	12.53 (6.67)	14.08 (9.31)	12.74 (7.13)	13.59 (9.78)

** $p<.01$; *** $p<.001$

Table 6.4

Mean percent of total errors (standard deviations) on card sorting tests for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS	VPT	SDRT	SSF	SSB**	SST
F value	(1,41)=0.94	(1,37)=2.54	(1,32)=3.70 p=.06	(1,39)=3.08 p=.08	(1,36)=0.91	(1,38)=12.05	(1,34)=4.00 p=.05
High	8.99 (4.49)	8.91 (5.09)	8.40 (4.96)	9.54 (5.47)	9.89 (5.46)	7.04 (3.23)	8.84 (5.39)
Low	12.82 (9.37)	13.60 (8.63)	13.96 (10.07)	13.39 (8.04)	14.06 (11.08)	12.81 (7.99)	15.18 (12.00)

** $p<.01$

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Backwards, with a trend towards significance for the Visual Patterns Test, Spatial Delayed Response Task, and Spatial Span Total, suggesting that a higher percentage of errors were made by low scorers than high scorers on the visuospatial tasks (Table 6.4).

The group x card sorting test interaction for Letter Number Span only, showed a trend towards significance, $F(1,37)=3.30$, $p=.07$ (Figure 6.1). Further analysis revealed that whereas low scorers had a significantly higher percentage of total errors than high scorers on the MCST, $F(1,37)=12.49$, $p=.001$, there was no significant difference between groups on WCST, $F(1,37)=0.01$, $p=.97$. There was also a significantly higher percentage of total errors on the MCST than on the WCST for both low scorers, $F(1,16)=21.97$, $p<.001$, and high scorers, $F(1,21)=8.19$, $p=.009$.

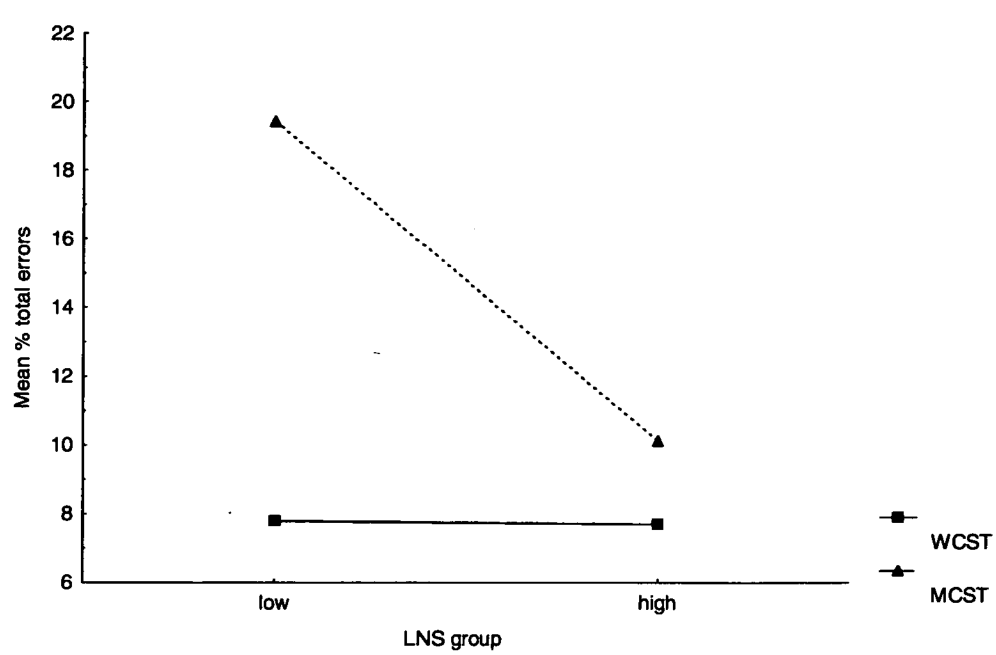

Figure 6.1. Mean percent of total errors on WCST and MCST for high and low scorers on Letter Number Span (LNS).

Subsequent one-way ANOVAs were performed on each working memory task for WCST and MCST separately. Only low scorers on Spatial Span Backwards had a significantly higher percentage of total errors on WCST (Table 6.5) whereas low scorers on all working memory tasks (except Spatial Span Forwards and Spatial Span Total) had significantly higher percentages of total errors on MCST (Table 6.6).

Perseverative and nonperseverative errors

Separate 2 [group: high scorers, low scorers] x 2 (error type: perseverative, nonperseverative) ANOVAs were performed, with group the between-subjects factor and error type the within-subjects factor, to assess the types of errors committed on each card-sorting test. Due to the skewness of the data, logarithm transformations were conducted prior to analysis (see Appendix A). In the following tables (Tables 6.7-6.10) the F-values for the transformed variables are reported. There were significant main effects for group and error types but no significant interactions.

Significant main effects for error type indicated that participants in all working memory sets made significantly more perseverative than nonperseverative errors on the WCST (Table 6.7), whereas on the MCST participants in all working memory sets made significantly more nonperseverative than perseverative errors (Table 6.8). Significant main effects for group indicated that low scorers on Spatial Delayed Response Task, Spatial Span Backwards, and Spatial Span Total made significantly more errors (perseverative and nonperseverative) on WCST (Table 6.9) and low scorers on Letter Number Span, Visual Patterns Test, Spatial Delayed

Table 6.5

Mean percent of total errors (standard deviations) on WCST for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS	VPT	SDRT	SSF	SSB*	SST
F-value	(1,41)=0.01	(1,37)=0.01	(1,32)=0.43	(1,39)=0.53	(1,36)=0.15	(1,38)=6.38	(1,34)=2.60
High	7.51 (4.98)	7.70 (6.66)	7.94 (6.81)	7.99 (5.00)	8.52 (6.35)	5.08 (2.82)	7.22 (6.17)
Low	9.12 (8.21)	7.79 (5.78)	11.01 (9.38)	11.16 (8.78)	11.77 (10.70)	10.64 (8.19)	13.30 (11.32)

* $p<.05$

Table 6.6

Mean percent of total errors (standard deviations) on MCST for high and low scorers on each working memory task using logarithm transformed variables.

	DSB*	LNS**	VPT**	SDRT*	SSF	SSB**	SST
F-value	(1,41)=4.71	(1,37)=12.49	(1,32)=11.72	(1,39)=6.43	(1,36)=2.16	(1,38)=7.92	(1,34)=3.43 $p=.07$
High	10.48 (4.00)	10.13 (3.53)	8.87 (3.11)	11.09 (5.95)	11.27 (4.58)	9.00 (3.65)	10.47 (4.61)
Low	16.53 (10.54)	19.42 (11.49)	16.91 (10.76)	15.63 (7.31)	16.35 (11.47)	14.99 (7.79)	17.07 (12.68)

$p<.05$, ** $p<.01$

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 6.7

Mean number of perseverative and nonperseverative errors (standard deviations) on WCST for each working memory task using logarithm transformed variables.

	DSB**	LNS***	VPT***	SDRT**	SSF**	SSB***	SST**
F-value	(1,41)=12.73	(1,37)=19.26	(1,32)=22.10	(1,39)=8.62	(1,36)=9.96	(1,38)=20.20	(1,34)=10.40
Pe	6.90 (3.84)	6.46 (3.66)	7.73 (4.70)	6.92 (3.77)	8.36 (6.40)	7.25 (3.98)	8.16 (6.57)
Npe	6.23 (5.11)	5.38 (4.38)	6.38 (5.67)	5.97 (4.56)	7.07 (5.62)	5.67 (4.85)	7.02 (5.84)

** $p<.01$, *** $p<.001$

Table 6.8

Mean number of perseverative and nonperseverative errors (standard deviations) on MCST for each working memory task using logarithm transformed variables.

	DSB***	LNS***	VPT***	SDRT***	SSF***	SSB***	SST***
F-value	(1,41)=188.45	(1,37)=168.40	(1,32)=102.63	(1,39)=220.87	(1,36)=185.51	(1,38)=215.65	(1,34)=186.85
Pe	2.74 (4.21)	3.00 (4.33)	2.79 (4.30)	2.41 (2.69)	2.73 (4.31)	2.20 (2.60)	2.69 (4.44)
Npe	11.00 (4.24)	11.58 (4.25)	9.73 (4.34)	10.65 (3.75)	11.36 (4.21)	10.85 (4.47)	10.77 (4.41)

*** $p<.001$

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 6.9

Mean number of errors (perseverative and nonperseverative) and standard deviations on WCST for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS	VPT	SDRT	SSF	SSB**	SST*
F-value	(1,41)=1.91	(1,37)=0.28	(1,32)=1.96	(1,39)=3.98 *p*=.05	(1,36)=1.70	(1,38)=10.29	(1,34)=6.77
High	5.66 (3.38)	5.90 (4.69)	6.13 (4.43)	5.64 (3.10)	6.46 (4.27)	4.33 (1.50)	5.73 (4.10)
Low	7.22 (5.04)	5.98 (2.94)	8.09 (5.89)	8.19 (5.44)	8.73 (7.04)	7.74 (5.07)	9.67 (7.50)

* $p<.05$, ** $p<.01$

Table 6.10

Mean number of errors (perseverative and nonperseverative) and standard deviations on MCST for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS**	VPT**	SDRT*	SSF	SSB**	SST
F-value	(1,41)=1.62	(1,37)=7.41	(1,32)=7.75	(1,39)=5.96	(1,36)=1.19	(1,38)=8.67	(1,34)=2.02
High	5.60 (2.41)	5.79 (2.43)	4.66 (2.49)	5.85 (2.75)	5.91 (2.42)	4.96 (2.13)	5.57 (2.41)
Low	7.78 (4.95)	9.23 (5.23)	8.06 (5.04)	7.99 (3.71)	7.97 (5.12)	7.46 (3.88)	8.02 (5.68)

* $p<.05$, ** $p<.01$

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Response Task and Spatial Span Backwards made significantly more errors (perseverative and nonperseverative) on the MCST (Table 6.10).

Discussion

Experiment 1A aimed to investigate the role of working memory in card sorting test performance in a population of psychometrically identified schizotypic individuals. Previous studies had found that high schizotypic scorers produced significantly lower scores on working memory tasks and performed more poorly on the WCST than low schizotypic scorers. However, in the present experiment this did not occur. Contrary to what was expected there were no significant differences between high and low schizotypic scorers on any measure of working memory or card sorting test performance.

It is possible that the Schizotypal Personality Questionnaire-Brief (SPQ-B), being a shortened version of the original, lacked sensitivity for defining schizotypy in a high functioning university population. However, the SPQ-B has been shown to be significantly correlated with independent clinical ratings of DSM-III-R schizotypal traits in an undergraduate population and to adequately reflect the factors measured by the original 74-item Schizotypal Personality Questionnaire (Raine & Benishay, 1995). In the present study participants had scored in the top and bottom quartiles on the SPQ-B, which represented scores of 12 and above, or five and below. It could be argued that these cut-off scores were too liberal to adequately detect differences on cognitive performance but additional analyses of the top and bottom 10%, which represented scores of 15 and above or three and below, also showed no significant difference between the groups. In previous studies in which significant differences on WCST indices or working memory scores were found, schizotypy was determined according to the original 74-item Schizotypal Personality Questionnaire in sample sizes equivalent to the present study (Daneluzzo et al., 1998; Park & McTigue, 1997). Therefore, it may be that some participants with schizotypal traits achieved a lower score on the SPQ-B than they may have done on the original version and as such scored below the cut-off point in this study.

In studies that used the Psychosis-Proneness subscales to determine schizotypy and found significant differences between high and low scorers, the sample sizes were considerably larger (n=178-259) (Gooding et al., 1999; Tallent & Gooding, 1999). In the smaller sample sized studies participants had not been screened for substance abuse, neurologic or psychiatric disorders, or colour-blindness (Lenzenweger & Gold, 2000; Lenzenweger & Korfine, 1994; Park et al., 1995), which may have positively affected their results. As it has also been suggested that traits measured by the Perceptual Aberration Subscale are substantially different from those measured by the Cognitive-Perceptual factor of the Schizotypal Personality Questionnaire (Chen, Hsiao, & Lin, 1997), future studies in schizotypy may benefit from investigating the comparability of these two measures.

The hypothesis that a nonperseverative error score and a failure to maintain set score would be significantly correlated with working memory measures was only partially supported. Although the correlations were weak, the Madrid nonperseverative errors were significantly negatively correlated with visual and spatial working memory measures with a trend towards significance for the auditory tasks. Wisconsin nonperseverative errors, however, showed a trend towards significance for measures representing spatial working memory only. There was no significant correlation between Wisconsin failure to maintain set score and any working memory measure.

Although the hypotheses related to the personality variable were not supported, a review of the data suggested an overall relationship between working memory and card sorting test performance. Therefore, the card sorting test performance of participants who scored in the top and bottom 15% on each of the working memory tasks was analysed. The results showed that low scorers on working memory tasks representing all modalities made a higher percentage of total errors than high scorers. In addition, significantly more total errors were made on the MCST than on the WCST. An interaction also occurred for Letter Number Span in that low scorers made more errors on the MCST than high scorers but there was no significant difference between the groups on the WCST. An analysis of the type of errors was also conducted which indicated that on the WCST participants made significantly more perseverative than nonperseverative errors whereas the reverse occurred for the MCST with significantly more nonperseverative than perseverative errors.

To assess whether the present sample was typical of the general population a comparison was made between the group means on the working memory tasks and the standardization sample means. For the visual and spatial tasks although the study sample means were positively skewed at the 70^{th}-75^{th} percentile of the standardization sample, low scorers for each task still scored significantly more errors than high scorers. For the auditory working memory tasks the study sample means were comparable to the standardization means. Although the cut-off points for the study sample were

15^{th} and 85^{th} percentiles these represented the 25^{th} and 75^{th} percentiles in the standardization sample.

The present findings provide supporting evidence for the involvement of working memory in card sorting test performance, with low scorers in all modalities making significantly more errors than high scorers. However, the results were not equivalent for the two card sorting tests. In contrast to Cinan and Tanör's (2002) findings participants in this study made significantly more errors on the MCST, which provided no visual feedback from previous response cards. It may be that without visual feedback a greater load is placed on the central executive in terms of both memory and processing than is required when visual feedback is present. This could also explain the interaction for Letter Number Span, which, although an auditory task, requires greater maintenance and manipulation of information than Digit Span Backwards. As well, low scorers in all modalities on the MCST made a higher percentage of errors whereas on the WCST this only occurred for low scorers in the spatial working memory task. This seems to suggest that on performance of the MCST not only is a greater load placed on the central executive but that there is also greater involvement of both slave systems, the phonological loop and visuospatial sketchpad. Alternatively, it may be that the MCST is a more sensitive task than the WCST in detecting reduced working memory ability. In their study with prefrontal patients, older age-matched controls, and a younger group of controls, Barceló and Knight (2002) found that the standard errors of measurement were greatly reduced for the control participants and suggested that performance on the MCST is sensitive to even minor deviations from normality.

The dissociation with regards to the quality of errors made on the two tests was a surprising result. Gold et al. (1997) suggested that working memory might only contribute to WCST performance to a certain threshold beyond which other cognitive variables become primary predictors of perseveration. However, this explanation does not seem appropriate for this generally high functioning undergraduate sample who were stratified according to working memory ability. Hartman et al. (2001, 2003) suggested that poorer performance on WCST may be due to a reduction in the ability to update information in working memory. For the present sample, as with normal elderly adults (Hartman et al., 2001), if information from the verbal feedback was not properly encoded then the chance of a perseverative error being made on the next trial was one in three or one in two if an incorrect response was made. Disclosure of the sorting criteria as in the MCST may have reduced the tendency to choose a perseverative response without altering overall performance with regards to working memory ability. Another explanation relates to the difference in visual feedback between the two card sorting tests. As noted by Cinan and Tanör (2002), when previous response cards are removed from view the tendency to match the current to the previous response card (i.e., a perseverative error) is significantly reduced which could also account for fewer perseverative errors being made on the MCST.

Although the overall results suggest that reduced or impaired working memory ability, irrespective of modality, contributes to poorer performance on card-sorting tests, the substantial differences in performance on the tests were an unexpected finding. A closer inspection of the two tasks, however, highlighted the procedural differences between them in addition to the presence or absence of visual feedback. In the MCST participants are required to complete 137 trials irrespective of the categories achieved whereas completion of the WCST is either after six completed categories or 128 trials. Participants are informed of the sorting criteria prior to commencement of the MCST whereas no information regarding the sorting criteria is provided in the WCST. The response cards for the MCST are unambiguous so that a match to a key card can only be made according to one of the three characteristics (colour, number, shape). In the WCST many of the response cards are ambiguous which means that a correct match can be made according to more than one characteristic. And finally, the difference in perseverative error definition may have impacted on the comparability of the two tests even though that used in the MCST is the same as in Nelson's (1976) modified WCST version. In the MCST a perseverative error is defined as an incorrect response that is the same as the immediately preceding incorrect response. In the WCST a perseverative error is defined as an incorrect response to a new category, which would have been a correct response for the immediately preceding category. Even though not all procedural differences could be addressed post hoc it seemed appropriate to revisit and rescore the data in accordance with a uniform error definition to gain a better understanding of the results before proceeding with further investigations into the role of working memory in card-sorting test performance.

CHAPTER 7

Experiment 1B: Card Sorting Data Revisited

The findings from Experiment 1A suggested that the performance on card sorting tests is inversely related to working memory ability. An effect of visual feedback was also found with significantly more errors occurring on the card-sorting test (MCST) in which previous response cards did not remain in view (no visual feedback). However, other differences in procedure between the WCST and MCST, such as card characteristics, test length, instructions, and error definitions may have confounded the results. Although not all differences can be addressed post hoc a direct comparison between the card sorting tests is possible by omitting all ambiguous cards from the WCST and redefining the errors in accordance with the MCST. Therefore, the aim of the present study was to re-examine the relationship between working memory ability and card sorting test performance after rescoring the data obtained in Experiment 1A.

Method

Participants

The sample consisted of Psychology 1 undergraduates from Experiment 1A whose scores were in the top or bottom 15% of scores on any of the working memory tasks (see Table 6.2).

Materials

Measures of executive function, and auditory, visual, and spatial working memory were the same as for Experiment 1A.

Procedure

To enable a direct comparison between responses on the WCST and the MCST from Experiment 1A, WCST responses were rescored after omitting all responses to ambiguous cards. Remaining responses were scored according to Barceló and Knight's (2002) MCST criteria and error percentages were calculated for all error types as the number of trials on the WCST varied between participants. For clarity, a review of the scoring criteria for the MCST is as follows:

- The first response of a new category is not counted as an error following correct feedback on the last response of the previous category.
- An *efficient error* is defined as an incorrect response in the second trial only of each category, which is different from the previous response, indicating an appropriate trial and error strategy.
- A *random error* is defined as an incorrect response that is different from the immediately preceding response.
- A *perseverative error* is defined as an incorrect response that is the same as the immediately preceding incorrect response.

Results

As for Experiment 1A the data were analysed by comparing the top and bottom 15% of scores on all working memory tasks with measures on the rescored Wisconsin (rWCST) and Madrid (MCST) Card Sorting Tests. Separate 2 [group: high scorers, low scorers] x 2 (card sorting test: rWisconsin, Madrid) ANOVAs were performed on all working memory tasks with the between-subjects factor being group and the within-subjects factor being the card-sorting task. The dependent variables were percentages of total errors, efficient errors, random errors, and perseverative errors for both card-sorting tests. As with previous analyses, Levene's Test of Equality indicated a violation of homogeneity, with the data positively skewed. Therefore, the following analyses were performed using logarithm transformations, which provided the best fit (Appendix B). No transformations were required for the percentage of efficient errors.

Percentage of total errors (efficient, random, and perseverative)

A significant main effect for card sorting test for the selected sample of participants in the Digit Span Backwards, Letter Number Span, and Spatial Delayed Response Task, with a trend towards significance for the Spatial Span Backwards sample indicated a significantly higher percentage of total errors were made on the MCST than on the rWCST (Table 7.1). There was also a significant main effect for group indicating that low scorers on each of the working memory tasks (except Letter Number Span and Spatial Span Forwards) made a significantly higher percentage of total errors than high scorers (Table 7.2). There were no significant interactions on any working memory task.

Percentage of total errors (excluding efficient errors)

There were no significant differences between the percentage of total errors (excluding efficient errors) made on the MCST and rWCST for all working memory tasks, except Letter Number Span in which significantly more errors were made on the MCST than on the rWCST (Table 7.3). However, low scorers on each of the working memory tasks (except Digit Span Backwards and Spatial Span Forwards) made a significantly higher

Table 7.1.

Mean percent of total errors (standard deviations) on the rWCST and MCST for each working memory task using logarithm transformed variables.

	DSB**	LNS***	VPT	SDRT*	SSF	SSB	SST
F value	(1,41)=8.76	(1,37)=13.21	(1,32)=1.08	(1,39)=4.42	(1,36)=1.01	(1,38)=3.20 p=.08	(1,34)=1.39
rWCST	10.89 (10.46)	9.31 (9.02)	12.42 (11.44)	10.71 (9.86)	13.77 (12.43)	11.20 (10.68)	13.13 (12.91)
MCST	14.00 (8.89)	14.18 (9.18)	12.65 (8.61)	12.53 (6.67)	14.08 (9.31)	12.74 (7.13)	13.59 (9.78)

* p<.05; ** p<.01, *** p<.001

Table 7.2.

Mean percent of total errors (standard deviations) for high and low scorers on each working memory task using logarithm transformed variables.

	DSB*	LNS	VPT*	SDRT*	SSF	SSB**	SST*
F value	(1,41)=5.04	(1,37)=3.26 p=.08	(1,32)=5.85	(1,39)=4.26	(1,36)=2.75	(1,38)=10.70	(1,34)=6.97
High	9.43 (6.19)	9.50 (6.5)	9.38 (6.27)	9.98 (6.92)	10.99 (6.88)	7.55 (4.04)	9.50 (6.67)
Low	14.61 (11.04)	14.65 (10.07)	16.08 (11.91)	15.16 (9.95)	16.29 (12.87)	14.62 (9.97)	16.66 (13.85)

* p<.05; ** p<.01

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 7.3.
Mean percent of total errors (standard deviations) excluding efficient errors on the rWCST and MCST for each working memory task using logarithm transformed variables.

	DSB	LNS**	VPT	SDRT	SSF	SSB	SST
F value	(1,41)=2.77	(1,37)=8.76	(1,32)=0.30	(1,39)=1.68	(1,36)=0.00	(1,38)=0.51	(1,34)=0.09
rWCST	8.42 (10.04)	6.86 (8.76)	9.47 (11.06)	8.05 (9.21)	10.80 (13.15)	8.72 (9.90)	10.43 (13.60)
MCST	8.68 (9.23)	9.29 (9.45)	7.92 (8.99)	7.57 (6.64)	8.70 (9.59)	7.68 (6.79)	8.47 (9.99)

**p<.01

Table 7.4.
Mean percent of total errors (standard deviations) excluding efficient errors for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS	VPT*	SDRT	SSF	SSB***	SST*
F value	(1,41)=2.29	(1,37)=3.80 p=.06	(1,32)=4.96	(1,39)=3.98 p=.05	(1,36)=1.73	(1,38)=16.61	(1,34)=6.59
High	5.71 (5.42)	5.82 (6.33)	5.68 (6.15)	6.28 (6.20)	6.96 (6.77)	3.93 (3.47)	5.54 (6.36)
Low	10.59 (11.29)	11.00 (10.02)	12.10 (12.02)	11.10 (10.22)	12.02 (13.73)	10.75 (9.37)	13.82 (14.76)

*p<.05; **p<.01, ***p<.001

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 7.5.
Mean percent of efficient errors (standard deviations) on rWCST and MCST for each working memory task.

F value	DSB*** (1,41)=57.48	LNS*** (1,37)=29.44	VPT** (1,32)=14.06	SDRT*** (1,39)=19.42	SSF*** (1,36)=17.66	SSB*** (1,38)=27.91	SST*** (1,34)=18.25
rWCST	2.42 (1.80)	2.43 (2.00)	2.89 (2.16)	2.66 (2.21)	3.23 (2.36)	2.42 (2.12)	2.91 (2.31)
MCST	5.38 (1.90)	4.88 (1.53)	4.83 (1.97)	4.94 (1.71)	5.48 (1.81)	5.15 (1.99)	5.21 (1.84)

** $p<.01$; *** $p<.001$

Table 7.6.
Mean percent of efficient errors (rWCST + MCST) and standard deviations for high and low scorers on each working memory task.

F value	DSB (1,41)=0.35	LNS (1,37)=0.01	VPT (1,32)=0.80	SDRT (1,39)=0.63	SSF (1,36)=1.67	SSB (1,38)=0.83	SST (1,34)=0.56
High	3.75 (1.93)	3.65 (1.74)	3.65 (2.04)	3.69 (2.03)	4.05 (2.01)	3.53 (1.76)	3.90 (2.03)
Low	4.00 (1.81)	3.64 (1.84)	4.10 (2.11)	4.03 (1.81)	4.60 (2.13)	3.93 (2.24)	4.24 (2.14)

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

percentage of errors than high scorers (Table 7.4). There were no significant interactions on any working memory task.

Percentage of efficient errors

As illustrated in Table 7.5 significantly more efficient errors were made on the MCST than on the rWCST for all working memory tasks. However, there was no significant difference between high and low scorers on any working memory task (Table 7.6).

Percentage of random errors

For Letter Number Span only, there was a significant main effect for card sorting test, $F(1,37)=14.78, p<.001$, and a trend towards a significant group x card sorting test interaction, $F(1,37)=3.05, p=.09$ (Figure 7.1). Further analysis revealed that whereas low scorers made a significantly higher percentage of random errors on MCST than high scorers, $F(1,37)=8.79, p<.01$, there was no significant difference between the groups on rWCST, $F(1,37)=0.01, p=.91$. Low scorers also had a significantly higher percentage of random errors on MCST than on rWCST, $F(1,16)=13.70, p<.01$, whereas there was no significant difference between percentage of random errors on the card sorting tests for high scorers, $F(1,21)=2.54, p=.13$.

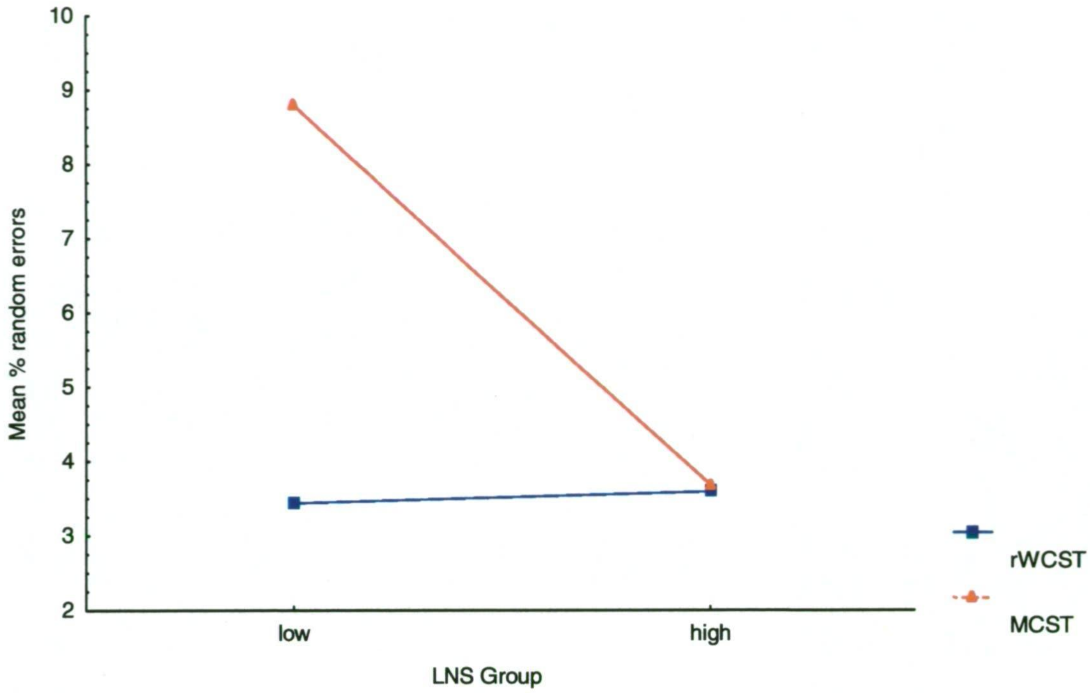

Figure 7.1. Mean percent random errors on MCST and rWCST for high and low scorers on Letter Number Span (LNS).

For all other working memory task samples there was no significant difference between the percentage of random errors made on the MCST and rWCST except for Digit Span Backwards in which more random errors were made on the MCST (Table 7.7). However, low scorers on each of the visuospatial working memory tasks (Visual Patterns Test, Spatial Delayed Response Task, Spatial Span Backwards, Spatial Span Total)) made a significantly higher percentage of random errors than high scorers (Table 7.8).

Percentage of perseverative errors

No significant group x card sorting test interactions were found for any of the working memory tasks. As can be seen in Table 7.9 for all working memory tasks there were no significant differences between the percentage of perseverative errors made on the MCST and rWCST. However, low scorers on

Table 7.7.
Mean percent of random errors (standard deviations) on rWCST and MCST for each working memory task using logarithm transformed variables.

	DSB*	LNS***	VPT	SDRT	SSF	SSB	SST
F value	(1,41)=4.65	(1,37)=14.78	(1,32)=0.64	(1,39)=3.05 *p*=.09	(1,36)=0.11	(1,38)=1.60	(1,34)=0.31
rWCST	4.98 (5.65)	3.52 (4.59)	5.07 (5.57)	4.46 (4.95)	5.76 (5.40)	4.84 (5.32)	5.50 (5.63)
MCST	5.52 (4.44)	5.90 (4.65)	4.96 (4.48)	4.96 (3.82)	5.78 (5.45)	5.26 (4.24)	5.59 (5.72)

*p<.05; ***p<.001

Table 7.8.
Mean percent of random errors (rWCST + MCST) and standard deviations for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS	VPT*	SDRT*	SSF	SSB***	SST**
F value	(1,41)=1.48	(1,37)=2.70	(1,32)=6.86	(1,39)=4.14	(1,36)=2.18	(1,38)=18.93	(1,34)=7.74
High	3.98 (3.67)	3.63 (3.75)	3.31 (3.48)	3.83 (3.44)	4.37 (3.84)	2.54 (2.36)	3.56 (3.66)
Low	6.16 (5.63)	6.11 (4.60)	6.94 (2.87)	6.59 (5.62)	6.89 (12.49)	6.56 (5.24)	7.76 (6.66)

*p<.05; **p<.01; ***p<.001

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 7.9.
Mean percent of perseverative errors (standard deviations) on the rWCST and MCST for each working memory task using logarithm transformed variables.

	DSB	LNS	VPT	SDRT	SSF	SSB	SST
F *value*	(1,41)=0.05	(1,37)=0.23	(1.32)=0.81	(1,39)=0.04	(1,36)=1.02	(1,38)=0.55	(1,34)=0.91
rWCST	3.47 (4.93)	3.34 (4.65)	4.46 (5.87)	3.59 (4.84)	5.03 (9.17)	3.93 (5.18)	4.98 (9.41)
MCST	3.15 (5.19)	3.38 (5.36)	2.96 (5.12)	2.61 (3.20)	2.91 (4.36)	2.41 (2.95)	2.87 (4.48)

Table 7.10.
Mean percent of perseverative errors (rWCST + MCST) and standard deviations for high and low scorers on each working memory task using logarithm transformed variables.

	DSB	LNS*	VPT*	SDRT	SSF	SSB**	SST*
F value	(1,41)=3.24 *p*=.08	(1,37)=5.12	(1,32)=4.97	(1,39)=3.65 *p*=.06	(1,36)=1.66	(1,38)=10.74	(1,34)=5.65
High	1.78 (2.05)	2.18 (3.05)	2.42 (3.24)	2.44 (3.17)	2.56 (3.33)	1.46 (1.76)	2.03 (3.08)
Low	4.42 (6.19)	4.88 (6.05)	5.16 (6.83)	4.51 (5.21)	5.12 (8.50)	4.19 (4.70)	6.05 (9.25)

*p<.05, **p<.01

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 7.11.

Mean percent of random and perseverative errors (standard deviations) on rWCST for each working memory task using logarithm transformed variables.

	DSB*	LNS	VPT	SDRT	SSF**	SSB	SST*
F value	(1,41)=7.17	(1,37)=2.08	(1.32)=2.62	(1,39)=3.03 *p*=.09	(1,36)=9.22	(1,38)=3.16 *p*=.08	(1,34)=6.68
Re	4.98 (5.65)	3.52 (4.59)	5.07 (5.57)	4.46 (4.95)	5.76 (5.40)	4.84 (5.32)	5.50 (5.63)
Pe	3.47 (4.93)	3.34 (4.65)	4.46 (5.87)	3.59 (4.84)	5.03 (9.17)	3.93 (5.18)	4.98 (9.41)

$^*p<.05$; $^{**}p<.01$

Table 7.12.

Mean percent of random and perseverative errors (standard deviations) on MCST for each working memory task using logarithm transformed variables.

	DSB***	LNS***	VPT***	SDRT***	SSF***	SSB***	SST***
F value	(1,41)=69.32	(1,37)=31.81	(1,32)=17.35	(1,39)=37.68	(1,36)=32.20	(1,38)=39.02	(1,34)=32.67
Re	5.52 (4.44)	5.90 (4.65)	4.96 (4.48)	4.96 (3.82)	5.78 (5.45)	5.26 (4.24)	5.59 (5.72)
Pe	3.15 (5.19)	3.38 (5.36)	2.96 (5.12)	2.61 (3.20)	2.91 (4.36)	2.41 (2.95)	2.87 (4.48)

$^{***}p<.001$

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Table 7.13.
Mean percent of errors (random and perseverative) and standard deviations on rWCST for high and low scorers for each working memory task using logarithm transformed variables.

	DSB	LNS	VPT	SDRT	SSF	SSB**	SST*
F value	(1,41)=1.27	(1,37)=0.39	(1.32)=1.98	(1,39)=1.96	(1,36)=1.18	(1,38)=7.76	(1,34)=6.32
High	3.09 (3.95)	3.22 (4.91)	3.58 (4.87)	3.14 (3.64)	3.96 (4.82)	1.99 (2.38)	2.92 (4.45)
Low	5.04 (5.95)	3.70 (4.28)	6.10 (6.44)	5.92 (6.64)	6.55 (8.67)	5.82 (5.97)	7.83 (9.24)

*$p<.05$, **$p<.01$

Table 7.14.
Mean percent of errors (random and perseverative) and standard deviations on MCST for high and low scorers for each working memory task using logarithm transformed variables.

	DSB	LNS**	VPT**	SDRT*	SSF	SSB**	SST
F value	(1,41)=2.56	(1,37)=10.11	(1,32)=8.88	(1,39)=4.25	(1,36)=1.77	(1,38)=10.29	(1,34)=3.33 p=.07
High	2.66 (1.75)	2.59 (1.88)	2.15 (1.84)	3.13 (2.97)	2.97 (2.36)	2.01 (1.73)	2.66 (2.29)
Low	5.54 (5.87)	7.29 (6.37)	6.00 (6.11)	5.18 (4.19)	5.45 (6.08)	4.93 (3.98)	5.99 (6.67)

*$p<.05$, **$p<.01$

DSB=Digit Span Backwards; LNS=Letter Number Span; VPT=Visual Patterns Test; SDRT=Spatial Delayed Response Task; SSF=Spatial Span Forwards; SSB=Spatial Span Backwards; SST=Spatial Span Total

Letter Number Span, Visual Patterns Test, Spatial Span Backwards, and Spatial Span Total made a significantly higher percentage of perseverative errors than high scorers and there was a trend towards significance for Digit Span Backwards and Spatial Delayed Response Task (Table 7.10).

Perseverative versus random errors on each card sorting test

On the rWCST significantly more random than perseverative errors were made for the Digit Span Backwards, Spatial Span Forwards, and Spatial Span Total samples and there was a trend towards significance for the Spatial Delayed Response Task and Spatial Span Backwards samples (Table 7.11). However, on the MCST significantly more random than perseverative errors were made in all working memory groups (Table 7.12).

On the rWCST there was no significant difference between high and low scorers on the total of random and perseverative errors made except for Spatial Span Backwards and Spatial Span Total in which low scorers made more errors than high scorers (Table 7.13). On the MCST low scorers made significantly more random and perseverative errors than high scorers except in Digit Span Backwards and Spatial Span Forwards (Table 7.14).

Discussion

The purpose of the current study was to rescore the WCST so as to enable a more direct comparison between performance on the WCST and MCST. Ambiguous response cards on the original WCST were omitted and the remaining errors were defined according to Barceló and Knight's (2002) criteria as described on page 116.

Firstly, there were no significant differences between high and low scorers on any working memory task for the percentage of efficient errors but a significantly higher percentage of efficient errors were made on the MCST than on the rWCST. However, the higher score on the MCST may be an artefact of the rescoring process on the WCST as trials with ambiguous cards often followed the trial in which the sorting criterion was changed. The true responses on these trials are unknown so participants, prior to the presentation of the first unambiguous card, could have been using an appropriate trial and error strategy.

Consistent with the results in Experiment 1A, low working memory scorers made a significantly higher percentage of total errors than high scorers, both with and without the inclusion of efficient errors, on all working memory tasks representing all modalities. Significantly more errors were also made on the MCST than on the rWCST. However, when efficient errors were excluded the difference between card sorting tests disappeared except for Letter Number Span, which continued to show a significantly higher percentage of errors on the MCST.

Although the interaction for Letter Number Span found in Experiment 1A was no longer significant for the percentage of total errors, there was a trend towards a significant interaction for the percentage of random errors. The performance of low and high scorers was similar and non-significant on the rWCST but on the MCST low scorers made a significantly higher percentage of random errors than high scorers. As previously suggested the additional memory and processing load placed on the central executive by the absence of visual feedback in the MCST could account for this result. It is reasonable to assume that poorer performance on Letter Number Span, which is considered a dual task with high central executive involvement, could be attributed to a reduction in central executive ability. Therefore, a higher number of errors would be expected with an increase in task demands. However, there was no significant difference in performance between the groups on the rWCST, which one would expect if low scores on Letter Number Span were indicative of reduced central executive capacity. It may be that when visual feedback is absent the demands on the storage and/or rehearsal capacities of the slave systems are also increased such that any deficit in slave system ability would be detected. As no significant interactions were found on any other working memory tasks it is not possible to ascertain the contribution made by the individual systems to the respective card sorting tests. The phonological loop may be involved in the WCST to assist response inhibition when visual feedback is present and may also be involved in the MCST in the maintenance of verbal feedback and previous response card information when visual feedback is absent. The visuospatial sketchpad, on the other hand, may not be required when visual feedback is present but may be an important contributor in the storage and rehearsal of visual information when visual feedback is absent.

Direct comparisons between the card sorting tests with respect to the number of perseverative errors and random errors were not made in Experiment 1A due to the differences in error definition. However, the frequency of errors within each card-sorting test showed a dissociation with significantly more perseverative than nonperseverative errors being made on the WCST whereas significantly more nonperseverative than perseverative errors were made on the MCST. In comparison to this finding, with the rescoring and redefinition of perseverative errors on the WCST, an analysis of the rWCST showed either no significant difference between the percentage of random and perseverative errors made for each working memory task or, as with the MCST, a significantly higher percentage of random errors. On the original WCST a perseverative error is scored on ambiguous card trials if these are in-between two unambiguous card trials that have been scored as perseverative. That is, the ambiguous trials are scored as perseverative even though the examinee may have been using the correct sorting principle for these trials, unbeknownst to the examiner, but was unable to maintain set. This may in part explain the finding of more perseverative than nonperseverative errors on the original WCST in Experiment 1A that was reversed with the rWCST.

Although the current approach used to enable a direct comparison between the two card-sorting tests could be debated, the rescoring procedure has helped clarify and provide a possible explanation for the unexpected findings obtained in Experiment 1A. Overall, the results are mainly consistent across the two studies and with the hypothesis that working memory is a critical factor in card sorting test performance. Low scorers on all working memory tasks made a significantly higher percentage of total errors than high scorers (see Table 7.2). Moreover, the higher number of random than perseverative errors, particularly on the MCST (see Table 7.12), appears to confirm the importance of nonperseverative errors as a measure of working memory capacity. The differential effects of visual feedback and disclosure of the sorting criteria to performance requires further investigation particularly in light of the trend towards a significant interaction for random errors on Letter Number Span and the significantly higher percentage of total errors made on the MCST than on the WCST in Experiment 1A. With the application of consistent scoring definitions and procedure across tasks subsequent studies in this thesis will focus on the effect of visual feedback and examine the contribution of the individual components of working memory to card sorting test performance.

CHAPTER 8

Experiment 2: Dual-Task Pilot Studies

Researchers interested in investigating specific components of Baddeley's working memory model in nonclinical populations have used the dual-task paradigm. The concept of this paradigm is based on Baddeley's rationale (1986) that the introduction of a secondary task competing for the same storage space as a primary task should result in a deterioration in performance than if the two tasks were performed individually. As reviewed in Chapter 5, in the Wisconsin Card Sorting Test (WCST) literature secondary tasks postulated to interfere with the phonological loop and central executive have been used. Secondary tasks included digit span forwards and articulatory suppression for the phonological loop (Cinan & Tanör, 2002; Dunbar & Sussman, 1995) and summing a string of numbers, a tone detection task (Dunbar & Sussman, 1995), and random letter generation (Cinan & Tanör, 2002) for the central executive. Secondary tasks designed to interfere with the visuospatial sketchpad have so far not been used as a method of investigating the role of visuospatial working memory in WCST performance. As the aim of this thesis was to examine not only the role of working memory in WCST performance but to discern the contribution made by the individual components, appropriate secondary tasks that selectively interfere with the respective components and subcomponents were required.

In a two-experiment study Hecker and Mapperson (1997) investigated visual and spatial processing in working memory using computerised tasks with unattended flicker as the secondary task. Colours (exp 1) and black

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directional arrows (exp 2) were used to represent the visual aspect of the task. Participants were administered a series of trials in which each trial consisted of five randomly selected coloured squares or directional arrows presented in five randomly selected locations in a matrix. In the spatial condition, after stimulus presentation, the matrix remained on screen and participants were required to click on the squares in the same order as the presentation. In the visual condition, after stimulus presentation, the matrix disappeared and was replaced by an invariant horizontal display of either six colours or six directional arrows. Participants were required to click on the colours or arrows in the same order as the presentation. In the interference conditions either black and white or coloured flicker filled the entire screen area outside the matrix concurrently with presentation of the primary task. The use of unattended flicker as an interference task was based on the results of previous research, which showed that peripheral luminance flicker saturates the magnocellular pathway that processes spatial information whereas colour flicker saturates the parvocellular pathway that processes visual form. Hecker and Mapperson's results showed a double dissociation in both experiments with the black and white flicker significantly affecting performance in the spatial but not visual condition and coloured flicker affecting performance in the visual but not spatial condition.

As the intention for further experiments in this thesis was to employ a computerised version of card sorting test, using unattended flicker as a means of separating the involvement of the visual from the spatial subcomponent in test performance appeared to be a viable option. Therefore, a pilot study was undertaken in which participants were administered computerised versions of the Visual Patterns Tests (VPT: Della Sala et al., 1999) and Spatial Span test (Wechsler, 1997b), representing visual and spatial working memory respectively, with and without unattended flicker. Unfortunately, unattended flicker did not interfere with performance on either primary task. One possible explanation is the difference in the duration of the primary task presentation between the two studies. In the pilot study stimulus presentation was as per standardised instructions of one square per second for the Spatial Span and 3 s per pattern for the VPT, whereas in the Hecker and Mapperson experiments stimulus ontime was 278 ms. As the target cards presented in card sorting tests are not time limited, reducing the primary task presentation time was not an appropriate option as any results could not be extrapolated to card sorting tests. So, further investigations into the use of unattended flicker as a secondary task was discontinued. Furthermore, due to technical difficulties, the designing and programming of computerised versions of a card sorting test to further investigate the visual aspects of the test was not possible, thus attention turned to finding appropriate secondary tasks to incorporate with manual card sorting test procedures.

Two tasks that have been shown to consistently interfere with the phonological loop and visuospatial sketchpad are articulatory suppression and spatial tapping, respectively. Articulatory suppression involves the constant verbal repetition of a word, such as ‘the’, ‘blah-blah’, or ‘Monday’, which prevents the verbal or sub-vocal rehearsal of to-be-remembered stimuli presented in either the auditory or visual modality (Baddeley, 2001). Although the WCST is a visual task all characteristics of the cards (colour, number, shape) can be verbalised, therefore, the use of articulatory suppression as a secondary task to determine the contribution made by the phonological loop in WCST performance would appear to be the most appropriate.

Spatial tapping involves haptically tapping an unseen series of pegs on a board in a predetermined pattern. As a secondary task spatial tapping has been found to not only interfere with the visuospatial sketchpad per se but also to exert greater interference on the spatial subcomponent of the sketchpad than on the visual subcomponent (Della Sala et al., 1999; Logie & Marchetti, 1991; Pearson et al., 1999; Pickering et al., 2001). For example, in their study using the primary tasks of the Visual Patterns Test and the Corsi Blocks, Della Sala and colleagues found that performance on the Corsi Blocks was reduced significantly more by spatial tapping than by irrelevant pictures whereas irrelevant pictures reduced performance on the Visual Patterns Test significantly more than on the Corsi Blocks. The interference tasks in this study were performed during a 10 s retention interval. As spatial tapping could easily be performed concurrently with the primary task it would seem to be a suitable secondary task to use with manual card sorting. However, an appropriate visual interference task that could also be performed concurrently required additional consideration, which led to the following pilot study.

Pilot Study One: A Visual Interference Task

Visual interference tasks, which have been proposed to interfere with, or have direct access to, the visual store have included irrelevant patterns or pictures, such as dynamic visual noise, line drawings, and abstract paintings (Della Sala et al., 1999; Logie, 1995; Logie & Marchetti, 1991; McConnell & Quinn, 2000; Quinn & McConnell, 1996). However, experimental procedures have been mainly aimed at the effect on visual imagery tasks (e.g., Brooks

(1967) matrix; visual imagery of a previously performed task) and/or have been administered during a delayed retention interval of 10-36 s. One of the main challenges, therefore, was to find or design a suitable visual secondary task that could be administered concurrently with a visually presented primary task that was not a visual imagery task.

Andrade, Kemps, Werniers, May, and Szmalec (2002) conducted a series of experiments to examine whether dynamic visual noise would significantly reduce performance on visual working memory tasks involving matrices as it had been shown to do in McConnell and Quinn's (2000) visual imagery studies. No interference effects were found when dynamic visual noise was administered during a 4 s or 10 s retention interval with recall of the matrices as the dependent variable. Nor were there any interference effects when a recognition procedure was used and dynamic visual noise was introduced during the interstimulus interval so as to interfere with encoding of the visual task. As Logie and Marchetti (1991) and Della Sala et al. (1999) had found that irrelevant visual stimuli did disrupt memory for colour hues and matrix patterns Andrade et al. suggested, in line with Logie's (1995) view of working memory, that the interference task might need to be structured and meaningful to gain access to the visual store. That is, activation of a long-term memory representation is required to occupy and consequently disrupt the visual store.

Therefore, the requirements for a visual secondary task that would interfere with the rehearsal of visual information, so as to prevent encoding, and to enable it to be administered concurrently with manual card sorting, appeared to be that a) the interference stimuli must not involve colours, numbers, or geometric shapes, all of which would require inhibitory control, b) the stimuli must be structured and meaningful, and c) the duration of stimulus presentation must be 2-3 s, which is appropriate for a short-term memory task. Interleaving the secondary task with the primary task cards would allow the tasks to be performed concurrently, however, a certain amount of focussed attention would also be required otherwise participants could simply discard every alternate card. As directional arrows had been used as a visual task in a previous study (Hecker & Mapperson, 1997) a secondary task in which participants were required to monitor the direction of two consecutive arrows was piloted while performing the Visual Patterns Test. It was recognised that there would be some involvement of the central executive with this secondary task. However, as the processing and memory load required for the task appeared low, central executive involvement was thought to be minimal. The aim of this pilot study, therefore, was to determine whether the concurrent monitoring of geometric shapes would effectively disrupt performance on a visual working memory task.

Method

Participants

Thirteen female psychology undergraduates participated in the study for course credit.

Materials

The primary task used was a modification of the Visual Patterns Test (Della Sala et al., 1999). The Visual Patterns Test consists of a series of grids in which half of each grid is filled to create a visual pattern that is difficult to verbally encode (see Figure 8.1). In this modified version the grids progressed in size from a 10-celled matrix (5 filled cells) to a 26–celled matrix (13 filled cells) with complexity increasing with the addition of two cells being added to the previous grid. There were two patterns in the same size and shape grids at each level of complexity; a total of 18 patterns.

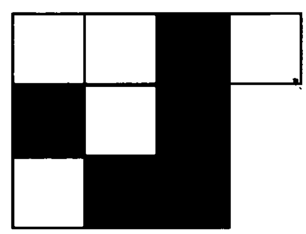

Figure 8.1. A 10-celled matrix from the Visual Patterns Test

The secondary interference task was a set of six arrows consisting of arrows pointing up, down, right, or left and double-headed arrows pointing vertically or horizontally (e.g., ← ↑ ↔) (Hecker & Mapperson, 1997).

Procedure

On each trial, participants were presented with a pattern for 3 s. After its removal and a delay period of 3 s they were given an empty grid of the same size and shape as the one presented and asked to reproduce the pattern by making marks in the grid. During the delay period participants viewed either a blank piece of paper or an arrow. Participants were presented with all 18 patterns to reproduce. There were three practice trials involving one each of a 4-celled, 6-celled, and 8-celled matrix.

In the interference condition participants were asked to monitor the direction of the arrows viewed during the delay period and to orally respond 'same' when two consecutive arrows were pointing in the same direction. The two parallel forms (A & B) of the Visual Patterns Test were used with the arrows presented during the delay period in Form B. Order of presentation was counterbalanced.

Design and Data Analysis

A repeated measures design was used with the independent variable being interference (with, without) and the dependent variable being the total number of correctly filled squares (not patterns). Means were calculated and analysed using a repeated measures ANOVA with an alpha significance level of .05. To determine the relationship between the correct number of squares filled and the correct monitoring of the arrows during the interference condition a Pearson's product-moment correlation was performed.

Results and Discussion

There was no significant correlation between the correct number of squares filled and the correct monitoring of the arrows during the interference condition either overall (r=.21, p=.49), at levels 6-9 (r=.16, p=.60), or at levels 10-13 (r=-.13, p=.68). This suggests that there was no trade-off in resource allocation to tasks.

A significant difference was found between the interference conditions, $F(1,12)$=6.48, p=.03. Fewer squares were correctly filled (M=122.62, SD=19.39) when there was a requirement to monitor the arrows during the delay period than when there was no such requirement (M=133.85, SD=12.40).

These results indicate that monitoring directional arrows while performing a visual working memory task significantly disrupts visual memory without requiring a trade-off in the allocation of attention away from the primary task. Thus, it would be an appropriate visual secondary task to incorporate with manual card sorting.

Pilot Study Two: A Central Executive Interference Task

Of the secondary tasks that have been designed and used to interfere with the central executive, random letter or number generation has been the most commonly used. However, this task involves a combined high memory load and processing load because participants are required to generate a series of numbers or letters at a certain rate while maintaining randomness by monitoring their tendency to produce well known sequences (e.g., A-B-C; I-B-M; 2-3-4). The capacity to maintain randomness has been found to decrease when the demands of the concurrent task are also high (Baddeley, 1966 as cited in Baddeley et al., 1998). Since card-sorting tests are considered to involve high processing and memory loads it seemed counterproductive to use such a demanding secondary task to investigate the role of the central executive.

As random generation is purported to disrupt the central executive because of the need to constantly switch retrieval plans, Baddeley and colleagues (Baddeley, 1996) investigated the use of a verbal trails task that had heavy switching demands but with minimal load on memory and other executive processes. The second subtest (B) of the Trail Making Test from the Halstead-Reitan battery is a pencil and paper test that requires participants to join a series of circles containing numbers and letters to produce a sequence that alternates between numbers and letters (i.e., A-1-B-2-C-3 etc.). As this test requires switching processes, Baddeley devised a verbal equivalent whereby participants were required to recite alternating numbers and letters while concurrently performing a random keypressing task. Baddeley reported that the randomness of keypressing was markedly reduced with this verbal trails task whereas simply reciting the alphabet or numbers had no effect. Although this would appear to be a viable alternative to random letter generation as a secondary task, other studies using the verbal trails have been difficult to find so confirmation of its effectiveness in disrupting performance on a visual executive task was required.

The Dot Matrix task is a visual executive task that requires participants to verify a matrix equation while simultaneously remembering a dot location in a 5 x 5 grid. This task requires the maintenance and manipulation of visual material and has been found to be significantly correlated with random number generation (Miyake et al., 2001). Therefore, the following pilot experiment aimed to determine the effectiveness of using verbal trails as a secondary task that interferes with the central executive when performed concurrently with a visual executive task.

Method

Participants

Ten female psychology undergraduate students participated for course credit.

Materials

The primary task was the Dot Matrix Task, which consists of a series of visual equations and 5 x 5 grids with a dot (Figure 8.2.). The secondary interference task was the Verbal Trails in which participants were required to verbalise continuously a series of alternating letters and numbers (A-1, B-2, C-3, D-4, E-5, F-6).

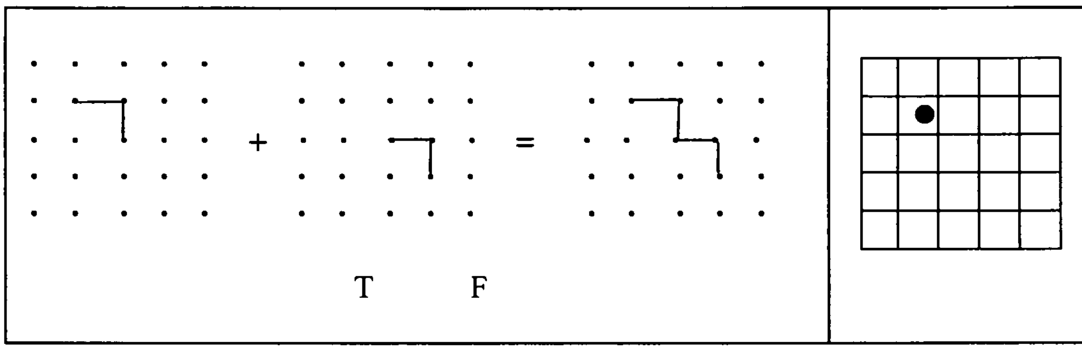

Figure 8.2. Dot Matrix Task.

Procedure

Participants were required to verify a visual equation while simultaneously remembering a dot location in a grid. In each trial an addition or subtraction visual equation was presented first for 4 s. Participants were asked to indicate on a response sheet whether the equation was true or false. Immediately following their response a grid containing one dot was presented for 2 s. After a number of equation-grid sets participants were given a blank grid and asked to reproduce as many of the dot locations as they could remember in any order. There were two practice trials with two equations and two dots each. The task consisted of two trials per level and five levels of difficulty, which progressively increased from two to six equation-grid sets per level; a total of 88 equation-grid sets with 10 response grids. In the interference condition participants were required to continuously verbalise a series of alternating letters and numbers (A-1, B-2, C-3, D-4, E-5, F-6) while performing the primary task.

Two versions of the Dot Matrix Task were used and presented in the same order, with presentation of the interference condition counterbalanced.

Design and Data Analysis

A repeated measures design was used with the independent variable being interference (with, without) and the dependent variables being the total number of dots correctly located and the number of equations correctly identified. Means were calculated and analysed using repeated measures ANOVAs with an alpha significance level of .05.

Results and Discussion

Means and standard deviations for the correct number of equations and dot locations are shown in Table 8.1. There was no significant difference between interference conditions in the number of equations correctly identified, $F(1,9)=1.41, p=.27$. However, there was a significant effect for dot location, $F(1,9)=27.24, p=.001$, in that significantly fewer dots were correctly located with concurrent performance of the secondary task.

Table 8.1
Means and standard deviations for the correct number of equations and dot locations with and without interference.

	With interference	Without interference
Equations	34.20 (2.44)	35.50 (3.50)
Dot locations	21.30 (5.17)	27.40 (6.06)

These results indicate that verbal trails significantly interferes with the central executive component of a visual task. Therefore, it would be a suitable alternative to random generation as a secondary task to use concurrently with manual card sorting.

CHAPTER 9

Experiment 3: Card Sorting and Dual-Tasking in a Nonclinical Population

The findings from Experiments 1A and 1B suggest that the presence or absence of visual feedback from previous response cards may have an effect on card sorting test performance. As discussed in Chapter 3, Cinan and Tanör (2002) are the only researchers who have considered the visual aspects of the Wisconsin Card Sorting Test (WCST). Nevertheless, other researchers investigating the cognitive processes underlying WCST performance have used modified versions in which the previous response cards were not visible (Barceló & Knight, 2002; González-Hernández et al., 2002; Monchi et al., 2001). In the design of their study, Cinan and Tanör examined the visual aspects of the task by comparing the performance of three groups under dual-task conditions where the secondary task of random letter generation was used. One group sorted to the standard three-dimensional key cards, that is, each key card represented a specific colour, number, and shape (e.g., one red triangle) to which a response card could be sorted. One group sorted to one-dimensional key cards (i.e., each key card represented only a colour, number, or shape) with the previous response cards remaining in view (with visual feedback), and the third group sorted to one-dimensional key cards with the previous response cards hidden (no visual feedback). Participants in each group were told exactly by which category to sort. Fewer errors were made when one-dimensional cards were used and still fewer when there was no visual feedback. The authors interpreted these results as evidence in support of response inhibition as a function of the central executive. They reasoned that in the three-dimensional condition more than one response was competing for output whereas there were no competing responses when one-dimensional cards were used and virtually none when previous response cards were hidden. Whilst this is a plausible explanation for a reduction in errors in the one-dimensional groups, it could also be hypothesised that the difference between the one-dimensional groups was due to a difference in the contribution made by the visuospatial sketchpad. It may be that when visual feedback was present there was no requirement for involvement of the visuospatial sketchpad. However, when visual feedback was absent, the visual aspects of the task may have been encoded directly into the visual store resulting in even fewer errors.

In Experiment 1A low scoring participants in all task modalities (auditory, visual, spatial) on working memory tasks made significantly more errors on the Madrid Card Sorting Test (MCST) in which there was no visual feedback. Conversely, on the WCST only low scoring participants on the spatial task made significantly more errors than high scorers. Although the sorting criteria were disclosed with the MCST, both tasks used three-dimensional key cards. According to Cinan and Tanör (2002), this would require response inhibition which is a function of the central executive. As described in Chapter 5, Cinan and Tanör also proposed involvement of the phonological loop in WCST performance, as did Dunbar and Sussman (1995). A higher number of errors on the no visual feedback task could simply reflect a greater memory and processing load. Alternatively, involvement of the visuospatial sketchpad may be required, in addition to the phonological loop and central executive, when visual feedback is absent. If so, then it could be argued that reduced or impaired visual working memory ability only becomes apparent when there is no visual feedback from previous response cards. Investigating all components of the working memory model, using the dual-task paradigm, could help clarify the roles of the individual components with respect to the presence or absence of visual feedback; the findings of which could have implications for the methodology used in future WCST research.

A perseverative error score is indicative of WCST performance, however, the chance of committing a perseverative error on any trial is one in three. On the WCST making a perseverative error could be due to an inability to shift set (cognitive inflexibility) or an inability to maintain set (working memory deficit) (Barceló & Knight, 2002). However, the use of ambiguous cards and the scoring procedure of the WCST preclude precisely determining why a perseverative error was made. In a nonclinical population, true perseveration would be expected to be minimal regardless of the number of errors committed. Nevertheless, in Experiment 1A significantly more perseverative than nonperseverative errors were made on the WCST whereas the same participants made significantly more nonperseverative than perseverative errors on the MCST. The MCST uses Nelson's (1976) definition of a perseverative error (see p. 25) and unambiguous cards. This suggests that the MCST procedure and scoring enable a more accurate distinction between cognitive inflexibility and a working memory deficit. This distinction has also been shown in studies with older adults (Hartman et al., 2001), patients with prefrontal lesions (Barceló & Knight, 2002), and patients with schizophrenia (Hartman et al., 2003). Therefore, examining the number of nonperseverative errors made, and more specifically, by examining random errors which reflect "an inefficient use of contextual information" (Barceló & Knight, 2002, p.350), seems more relevant with respect to working memory than focussing on the number of perseverative errors made.

The primary aim of Experiment 3 was to determine the contribution made to card sorting test performance by the phonological loop, central executive, and the visual and spatial subcomponents of the visuospatial sketchpad. A second aim was to examine whether the presence or absence of visual feedback differentially affects card sorting test performance with respect to the individual components of the working memory model.

Significantly more errors were made on the MCST in Experiments 1A and 1B in which no visual feedback from previous response cards was available. Given the anticipated increase in memory and processing loads, which would be required in the absence of visual feedback, it was hypothesised that overall more errors would be made in the no visual feedback than visual feedback condition and that the errors would be predominantly nonperseverative.

If the difference in card sorting test performance with and without visual feedback is only due to the difference in memory and processing loads then the effect of a concurrent secondary task in both conditions should be the same irrespective of the secondary task used. However, if involvement of the visual subcomponent of the visuospatial sketchpad, hereafter referred to as the *visual store*, is greater when visual feedback is absent then more errors would be expected to be made in the no visual feedback condition when card sorting is performed concurrently with the visual interference task.

A higher percentage of perseverative errors when visual feedback is present, was also hypothesised given Cinan and Tanör's (2002) findings. Their results indicated that more errors, in which response cards were matched to the immediately preceding response card instead of the key card (perseveration), were made when previous response cards remained visible.

Method

Participants

Ninety-six psychology undergraduates (m=13, f=83) from the University of Tasmania participated for course credit following a screening questionnaire (see Appendix D). Ages ranged from 18-45 years and exclusion criteria included colour-blindness, substance abuse, or neurological, psychiatric, or psychological problems. The study was approved by the Southern Tasmania Social Sciences Human Research Ethics Committee and written informed consent was obtained from all participants (Appendix D).

Materials

The primary task used was a modified version of the Wisconsin Card Sorting Test (Nelson, 1976) consisting of four key cards (one red triangle, two green stars, three yellow crosses, four blue circles) and 48 unambiguous response cards. Unlike Nelson's version participants completed all 48 trials irrespective of the number of categories achieved. Scoring was based on the following Barceló and Knight (2002) definitions. The sorting criterion for each category was predetermined with categories consisting of five, six, or seven trials so that participants could not predict the beginning of a new category. A *category achieved* score was defined as one in which there were neither perseverative nor random errors. For each condition a maximum of eight categories was achievable. A *perseverative error* was scored if the response was the same as the immediately preceding incorrect response. A *random error* was scored if the response was incorrect but different from the immediately preceding response. Consistent with these definitions an incorrect response on the first trial of a new category was not scored as an error unless it was a perseverative error and a random error on the second trial of a category was considered an efficient 'trial and error' response and therefore not scored as an error.

For the spatial tapping task a 10 cm square wooden board with four round pegs (2cm diameter x 2cm) positioned at each corner was used. The visual interference task was a set of 48 cards with each card depicting one of 10 directional arrows. The arrows pointed either up, down, right, left, diagonally right, left, up, or down, and double-headed arrows pointing vertically or horizontally (e.g., ← ↑ ↔ ↖).

Procedure

Participants were randomly assigned to one of four groups: articulatory suppression (AS), visual interference (VI), spatial tapping (ST), verbal trails (VTs). Each group performed a secondary task designed to interfere with the auditory, visual, spatial, or central executive components of working memory, respectively. Participants were tested individually in one session of approximately 30-45 min duration. Within the session each participant completed the modified WCST four times: with visual feedback (VF) (with and without a secondary task) and without visual feedback (NVF) (with and without a secondary task) in counterbalanced order.

The response cards were held face down in a dealer's shoe. Participants extracted one card at a time with their right hand. In the dual conditions participants were encouraged to practice the secondary task, except for the visual interference task, until they felt relatively competent before commencing the card-sorting test. The pace of the secondary task was monitored and a reminder was given if the rate slowed.

In the visual feedback condition each response card remained face-up and below the key card to which it was being sorted. Verbal feedback, on whether the sort was correct or incorrect, was given after each placement. In the no visual feedback condition the participant indicated the key card to which the response card was being sorted by placing the response card underneath the key card and then turning it face down in a central position in front of them before receiving verbal feedback.

In the *Articulatory Suppression* (AS) group the secondary interference task involved the continuous audible repetition of the word '*Monday*' at one word per sec, while performing the primary task.

In the *Spatial Tapping* (ST) group the secondary interference task required participants to tap the four pegs on the wooden board with their left hand in time with a metronome set at 1.5 sec per beat. The board, positioned in a diamond shape, was placed within a covered box so that it could not be seen by the participant.

In the *Visual Interference* (VI) group the secondary interference task consisted the interleaving of the 48 arrow cards with the 48 response cards. Participants were required to monitor the direction of the arrows viewed and to orally respond 'same' when two consecutive arrows were pointing in the same direction. This task was performed concurrently with sorting the response cards. In the no interference condition blank cards were interleaved with the response cards and participants were instructed to check each card so as not to miss a response card. During sorting the non-response cards were placed face down in front of the participant.

In the *Verbal Trails* (VTs) group the secondary interference task required participants to verbalise continuously a series of alternating letters and numbers (A-1, B-2, C-3, D-4, E-5, F-6) at approximately one letter-number set per sec, while performing the primary task

Design and data analysis

A 4 [group: articulatory suppression, spatial tapping, visual interference, verbal trails] x 2 (feedback: visual, no visual) x 2 (interference: with, without) mixed factorial design was used with the between-subjects factor being group and the within-subjects factors being feedback and interference. The dependent variables were the number of categories achieved, total number of errors, the number of random errors, and the percentage of perseverative errors scored on the card sorting tests.

Means and standard deviations were calculated and analysed using one-, two-, and three-way analyses of variance with an alpha significance level of .05.

Results

Means and standard deviations for all dependent variables for each group with and without visual feedback and with and without an interference task are reported in Table 9.1. All dependent variables were screened for normality. Total errors and random errors were found to be positively skewed

Table 9.1.
Mean score (standard deviation) on each dependent variable with and without an interference task and with (VF) and without (NVF) visual feedback for each group.

		Articulatory Suppression		Visual Interference		Spatial Tapping		Verbal Trails	
		Interference task		Interference task		Interference task		Interference task	
		with	without	with	without	with	without	with	without
Categories achieved	VF	5.0 (1.8)	6.3 (1.4)	6.2 (1.9)	6.1 (1.8)	5.7 (1.5)	6.5 (1.1)	5.1 (2.2)	6.0 (1.6)
	NVF	5.1 (1.4)	5.6 (1.3)	5.0 (2.6)	6.1 (2.0)	5.5 (1.9)	6.2 (1.3)	4.4 (2.1)	5.7 (1.7)
Total errors	VF	5.5 (5.3)	2.7 (3.2)	3.2 (5.0)	3.3 (4.0)	3.9 (3.5)	2.0 (2.0)	5.7 (5.2)	3.8 (3.9)
	NVF	5.2 (3.3)	3.9 (3.8)	7.2 (8.2)	4.0 (6.7)	4.4 (4.7)	2.8 (2.3)	8.3 (7.7)	4.5 (4.3)
Random errors	VF	3.6 (3.5)	1.8 (2.1)	2.4 (4.3)	2.5 (2.9)	2.7 (2.7)	1.5 (1.5)	4.1 (3.8)	2.4 (2.3)
	NVF	3.2 (2.2)	2.5 (2.7)	4.7 (5.6)	2.4 (4.4)	2.9 (2.8)	2.1 (1.7)	5.0 (4.3)	2.8 (2.7)
Percentage Perseverative errors	VF	33.1 (30.3)	24.6 (35.1)	27.9 (37.8)	20.7 (33.9)	27.2 (34.9)	13.6 (21.9)	22.6 (24.2)	21.7 (26.8)
	NVF	39.5 (33.3)	38.0 (35.0)	32.1 (31.3)	29.0 (31.3)	26.3 (30.5)	17.8 (24.6)	34.7 (22.5)	31.3 (28.3)

(Appendix D). Consequently, logarithm transformations, which produced the best fit, were used for all analyses of variance and the *F*-values reported for total errors and random errors are for the transformed variables.

Categories Achieved

A 4 [group] x 2 (feedback) x 2 (interference) ANOVA indicated significant main effects for feedback, $F(1,92)=13.34$, $p<.001$, and interference, $F(1,92)=33.56$, $p<.001$, which were qualified by a significant group x feedback x interference interaction, $F(3,92)=2.81$, $p=.04$. Further two-way ANOVAs were conducted for each group and are illustrated in Figure 9.1.

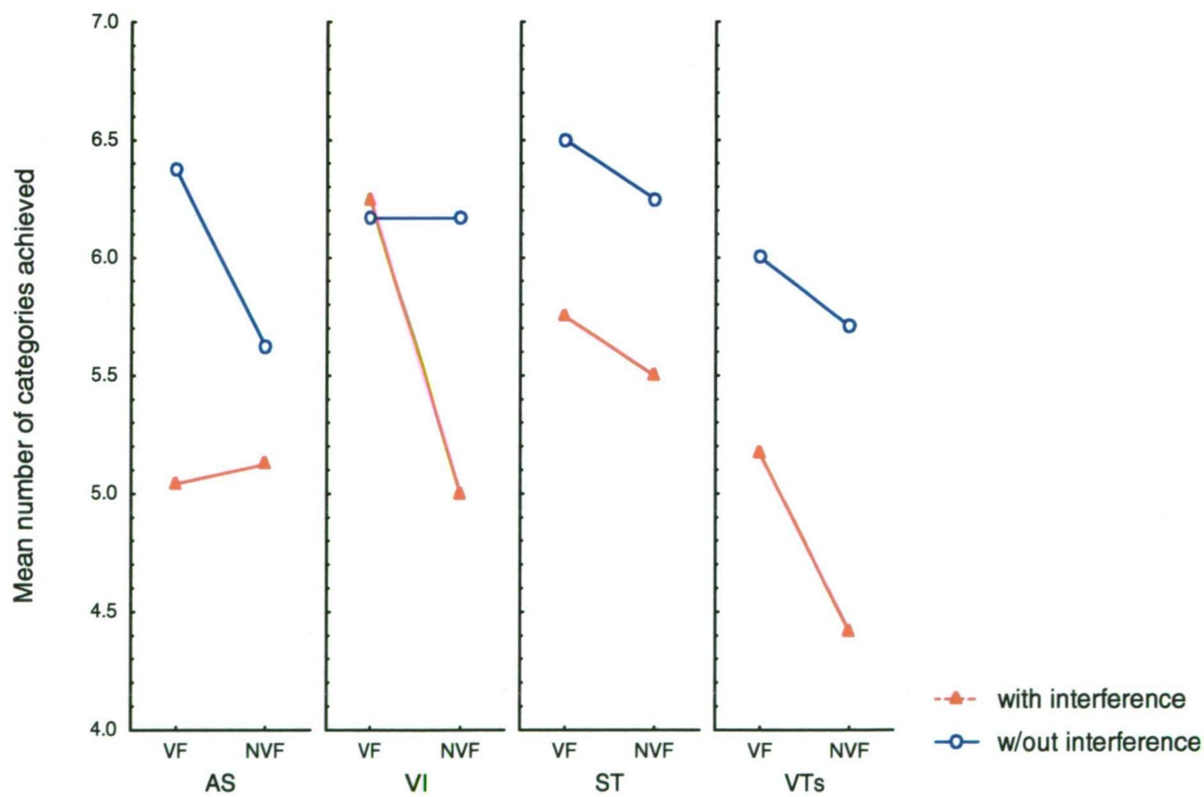

Figure 9.1. Mean number of categories achieved, with and without interference in the visual (VF) and no visual (NVF) feedback conditions, for the Articulatory Suppression (AS), Visual Interference (VI), Spatial Tapping (ST), and Verbal Trails (VTs) groups.

For the *Articulatory Suppression* (AS) group there was a significant main effect for interference, $F(1,23)=11.5$, $p<.01$, and a trend towards a significant feedback x interference interaction, $F(1,23)=3.38$, $p=.08$. One-way ANOVAs indicated that in the baseline no interference condition significantly more categories were achieved with visual feedback (VF) than with no visual feedback (NVF), $F(1,23)=5.69$, $p=.03$. With interference, there was no significant difference between the feedback conditions $F(1,23)=0.07$, $p=.79$. However, in the VF condition significantly fewer categories were achieved with interference than without interference, $F(1,23)=16.00$, $p<.001$, whereas in the NVF condition there was no effect of interference, $F(1,23)=1.81$, $p=.19$.

For the *Visual Interference* (VI) group there was a significant main effect for feedback, $F(1,23)=6.71$, $p=.02$, a trend towards a significant effect for interference, $F(1,23)=3.48$, $p=.07$ and a trend towards a significant feedback x interference interaction, $F(1,23)=3.77$, $p=.06$. One-way ANOVAs indicated that with interference significantly fewer categories were achieved with NVF than with VF, $F(1,23)=8.09$, $p<.01$, whereas there was no significant difference between the feedback conditions without interference $F(1,23)=0.00$, $p=1.00$. Moreover, significantly fewer categories were achieved with interference in the NVF condition, $F(1,23)=5.17$, $p=.03$, but there was no effect of interference in the VF condition, $F(1,23)=0.06$, $p=.81$.

For the *Spatial Tapping* (ST) group there was a significant main effect for interference only, $F(1,23)=6.53$, $p=.02$, indicating that with concurrent spatial tapping the number of categories achieved was significantly reduced in both visual and no visual feedback conditions.

For the *Verbal Trails* (VTs) group there were significant main effects for feedback, $F(1,23)=4.50$, $p=.04$, and interference, $F(1,23)=14.95$, $p=.001$, but there was no significant interaction, $F(1,23)=0.75$, $p=.39$. As illustrated in Figure 9.1 significantly fewer categories were achieved in the NVF condition and with concurrent reciting of verbal trails in both feedback conditions.

Total number of errors (logarithm transformed)

A 4 [group] x 2 (feedback) x 2 (interference) ANOVA indicated significant main effects for feedback, $F(1,92)=11.84$, $p=.001$, and interference, $F(1,92)=25.36$, $p<.001$, with a strong trend towards a significant group x feedback x interference interaction, $F(3,92)=2.47$, $p=.07$. Further two-way ANOVAs were conducted for each group and are illustrated in Figure 9.2.

For the *Articulatory Suppression* (AS) group there was a significant main effect for interference only, $F(1,23)=12.26$, $p<.01$, indicating that significantly more errors were made with concurrent articulatory suppression in both feedback conditions.

For the *Visual Interference* (VI) group there was a significant main effect for feedback, $F(1,23)=4.37$, $p=.048$, with a trend towards a significant feedback x interference interaction, $F(1,23)=3.49$, $p=.07$. Further one-way ANOVAs indicated that, with interference, in the NVF condition there was an increase in the total number of errors which verged on significance, $F(1,23)=4.22$, $p=.05$, whereas there was no effect of interference in the VF condition, $F(1,23)=0.35$, $p=.56$.

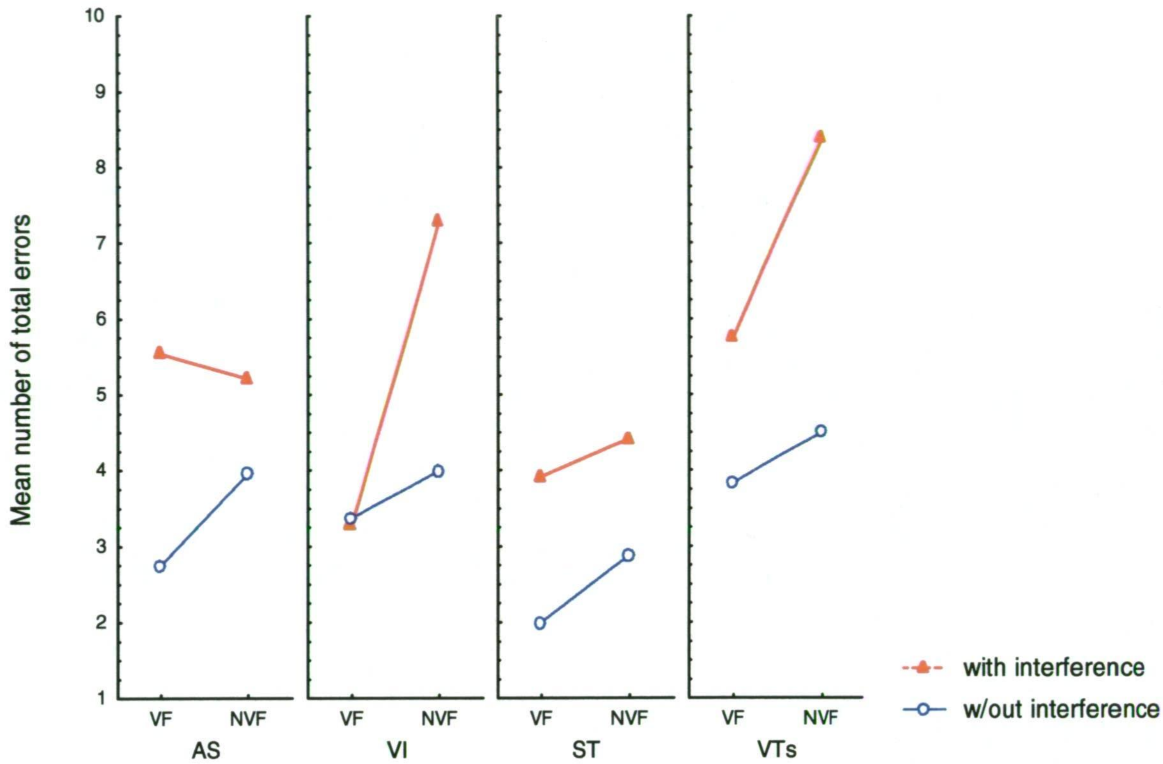

Figure 9.2. Mean number of total errors, with and without interference in the visual (VF) and no visual (NVF) feedback conditions, for the Articulatory Suppression (AS), Visual Interference (VI), Spatial Tapping (ST), and Verbal Trails (VTs) groups.

For the *Spatial Tapping* (ST) group there was a significant main effect for interference only, $F(1,23)=4.51$, $p=.045$, indicating that with concurrent spatial tapping significantly more errors were made in both feedback conditions.

For the *Verbal Trails* (VTs) group there were significant main effects for feedback, $F(1,23)=4.43$, $p=.046$, and interference, $F(1,23)=8.30$, $p<.01$ but there was no significant interaction $F(1,23)=0.10$, $p=.76$. As illustrated in Figure 9.2 significantly more errors were made in the NVF condition and with concurrent reciting of verbal trails in both feedback conditions.

Random errors (logarithm transformed)

A 4 [group] x 2 (feedback) x 2 (interference) ANOVA indicated significant main effects for feedback, $F(1,92)=4.26$, $p=.04$, and interference, $F(1,92)=17.41$, $p<.001$, which were qualified by a significant group x feedback x interference interaction, $F(3,92)=3.29$, $p=.02$. Further two-way ANOVAs were conducted for each group and are illustrated in Figure 9.3.

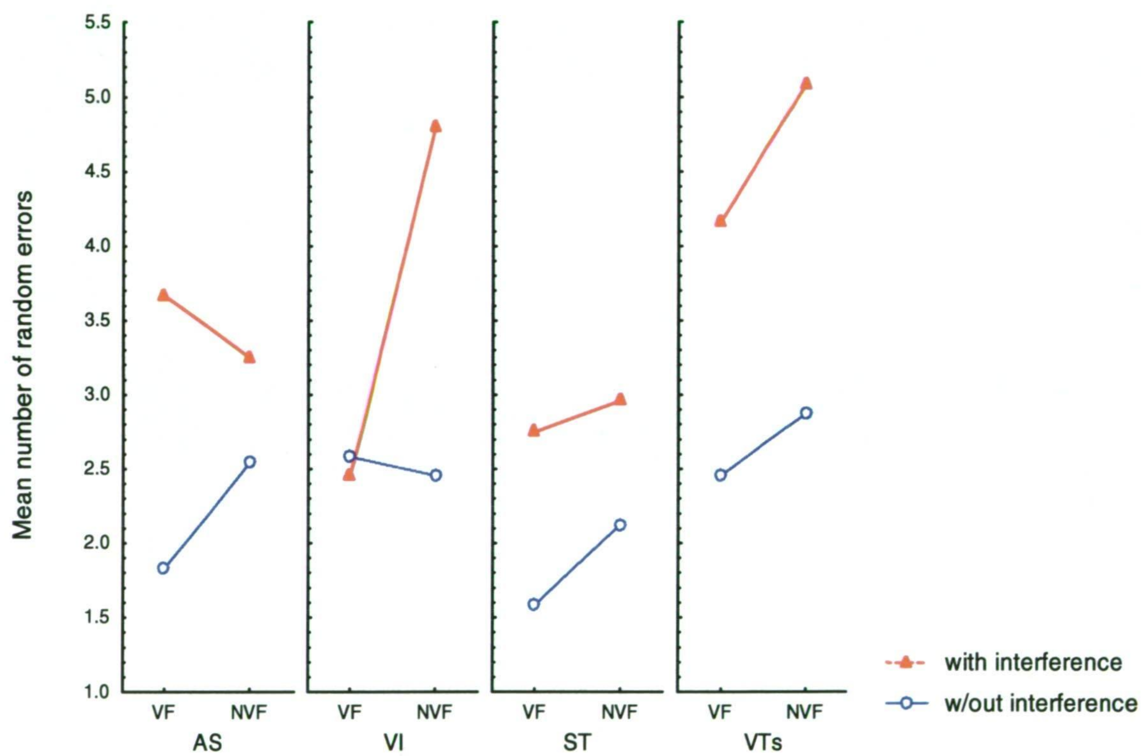

Figure 9.3. Mean number of random errors, with and without interference in the visual (VF) and no visual (NVF) feedback conditions, for the Articulatory Suppression (AS), Visual Interference (VI), Spatial Tapping (ST), and Verbal Trails (VTs) groups.

For the *Articulatory Suppression* (AS) group there was a significant main effect for interference only, $F(1,23)=8.75$, $p<.01$, indicating that significantly more random errors were made with concurrent articulatory suppression in both feedback conditions.

For the *Visual Interference* (VI) group there was a significant feedback x interference interaction, $F(1,23)=7.37$, $p=.01$. One-way ANOVAs showed no significant difference between feedback conditions when there was no interference. However, with interference, significantly more random errors were made in the NVF condition, $F(1,23)=6.71$, $p=.02$, but there was no effect of interference in the VF condition $F(1,23)=0.95$, $p=.34$.

For the *Spatial Tapping* (ST) group there was no significant main effect for feedback, $F(1,23)=.77$, $p=.39$, or for interference, $F(1,23)=1.80$, $p=.19$ and no significant interaction, $F(1,23)=.18$, $p=.67$.

For the *Verbal Trails* (VTs) group there was a significant main effect for interference only, $F(1,23)=8.53$, $p<.01$, indicating that significantly more random errors were made in both feedback conditions with concurrent verbal trails.

Percentage perseverative errors

A 4 [group] x 2 (feedback) x 2 (interference) ANOVA indicated significant main effects for feedback, $F(1,92)=6.06$, $p=.02$, and verging on significance for interference, $F(1,92)=3.92$, $p=.05$ but there were no significant interactions. As can be seen in Figure 9.4 a higher percentage of perseverative errors were made in the NVF condition across all groups and with the concurrent interference tasks in both feedback conditions.

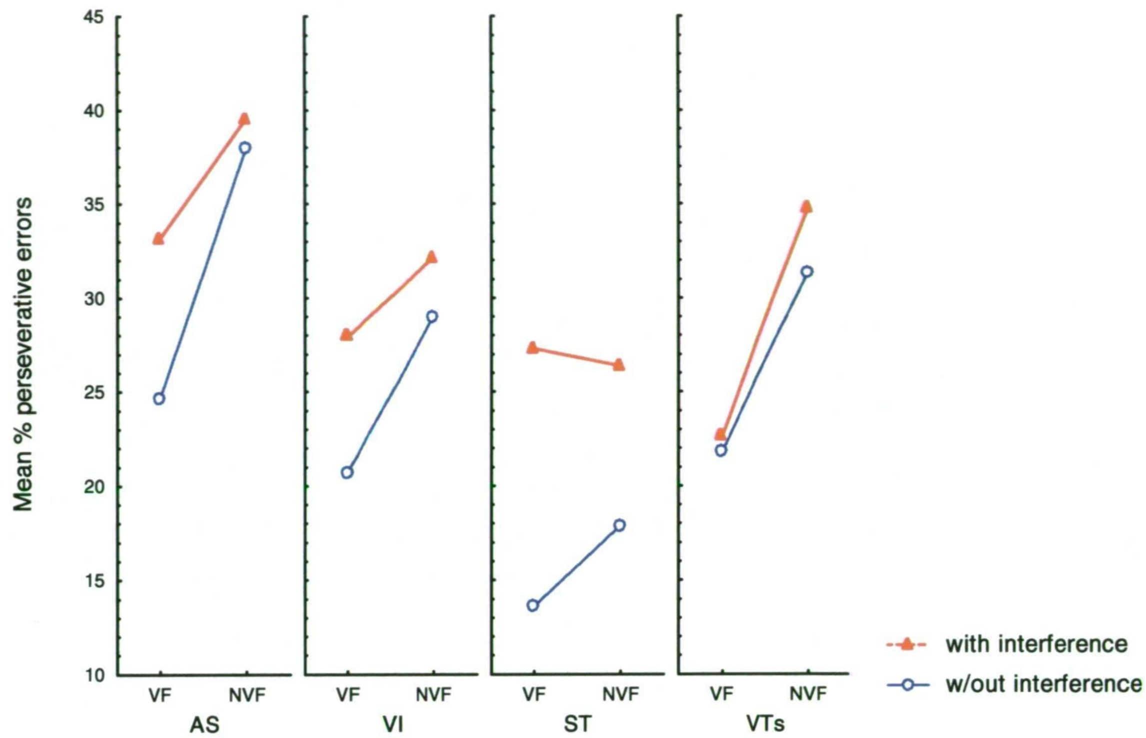

Figure 9.4. Mean percentage of perseverative errors, with and without interference in the visual (VF) and no visual (NVF) feedback conditions, for the Articulatory Suppression (AS), Visual Interference (VI), Spatial Tapping (ST), and Verbal Trails (VTs) groups.

Discussion

The aim of the present experiment was to investigate the involvement of the individual components of working memory in card sorting test performance with respect to the presence or absence of visual feedback. The hypothesis that significantly more errors would be made when there was no visual feedback from previous response cards was supported. Performance on the primary card-sorting test was also poorer when performed concurrently with a secondary task. However, the results were not consistent across the four groups with a significant three-way interaction found on most dependent measures. As this suggests some differentiation in the contribution made by the individual components of working memory, the findings pertaining to each group will initially be discussed separately.

In the *Spatial Tapping* (ST) group although fewer categories and more errors were made when there was no visual feedback the difference between feedback conditions did not reach significance. However, there was a significant adverse effect on performance with the addition of the secondary task. Logie (1995) described the concept of spatial working memory as incorporating movement either in the form of visual scanning or physical movement. The requirement of visual scanning of the key cards would not have been altered by the presence or absence of visual feedback. Therefore, the effect of spatial tapping on performance overall, supports previous findings (Gooding & Tallent, 2002; Park et al., 1995; Tallent & Gooding, 1999) that spatial working memory is involved in card sorting test performance.

Card sorting is a complex activity that requires the maintenance of multiple pieces of information in working memory. Even when the sorting criteria are disclosed, as in the present experiment, participants are required to hold 'on-line' information regarding the sorting rules, previous responses, and verbal feedback. Support for central executive involvement was provided by the results from the *Verbal Trails* (VTs) group in which significantly fewer categories were achieved and more errors were made in the dual-task condition. Performance was also significantly poorer in the absence of visual feedback. Even though a greater memory load and processing load could explain the higher number of errors and fewer categories in the no visual feedback condition, the lack of an interaction on any dependent measure suggests that the degree of central executive involvement is equivalent across feedback conditions.

Articulatory suppression is well supported in the literature as a secondary task that differentially interferes with the phonological loop by preventing the vocal or sub-vocal rehearsal of information. In the *Articulatory Suppression* (AS) group significantly fewer categories were achieved and more errors were made with articulatory suppression in both feedback conditions. This suggests that the phonological loop is involved in card sorting irrespective of whether visual feedback is present or absent. However, there is some indication that when visual feedback is present, involvement of the phonological loop is higher than when visual feedback is absent. On all dependent measures performance was affected more in the visual feedback condition with the addition of the secondary task than it was in the no visual feedback condition. Although the interactions did not reach significance there was a trend towards significance for the number of categories achieved. An impractically large sample may be required to detect what seems to be a subtle difference between the feedback conditions. Nevertheless this difference may represent the greater requirement for articulatory rehearsal in assisting with inhibitory control in the presence of competing visual information, as proposed by Cinan and Tanör (2002).

The most interesting results were found in the *Visual Interference* (VI) group. There was a significant feedback x interference interaction for the number of random errors made, as well as a trend towards significance for the number of categories achieved and the number of total errors. One anomaly in this group however, not present in the other three groups, was the absence of a difference between the visual feedback conditions when card sorting was performed alone. This finding is difficult to explain as all participants met the exclusion criteria, they were randomly assigned to groups, and the male to female ratio was equivalent across groups. It is possible that as participants in this group handled twice as many cards as in the other groups, attentional demands were higher. This seems unlikely, as the requirement was the same for both feedback conditions. However, another possibility is that the blank cards may have disrupted the processing of information in the visual feedback condition only. If the visual store is involved when visual feedback is absent but not present, then the blank cards would not have caused any interference in the no visual feedback condition but may have acted like a 'mask' in the visual feedback condition. Alternatively, it may be that as a group they had a greater working memory capacity by chance, which was not adversely affected by the increase in memory or processing load in the no visual feedback condition. Performance in both feedback conditions was still within the range of that of the other groups on all dependent measures.

Irrespective of this lack of difference in performance in the baseline no-interference condition, there was a significant difference between feedback conditions when card sorting was performed concurrently with the secondary task. When visual feedback was present there was no effect of interference on any dependent measure. However, when visual feedback was absent significantly fewer categories were achieved and more total and random errors were made in the dual-task condition. These results support the hypothesis that if the visual store is involved in card sorting then more errors would be made with interference in the absence of visual feedback. The present results suggest that the visual store contributes to performance but only when there is no visual feedback from previous response cards. In Logie's (1995) view of visuospatial working memory "the visual store is subject to decay and to interference from new information coming in" (p.126). It may be that in the visual feedback condition reliance is placed on the phonological loop to assist in inhibiting competing visual information whereas in the no visual feedback condition the static visual images of the response cards activate long-term memory representations enabling entry into the visual store. As there is then no competing visual interference the information becomes accessible to the central executive. The fact that the visual feedback condition in this group alone was the only one not adversely affected by the addition of a secondary task supports this proposal.

It could be argued that the secondary visual interference task used was really an n-back task, which is considered to be a central executive task. An n-back task is one that requires a participant to recall a stimulus presented n trials earlier. Although there is no disputing that the task fits the n-back paradigm it merely required the matching of static visual images to the immediately preceding trial involving maintenance but no manipulation, unlike the verbal trails task. Also, if the visual interference task was a central executive task the results should have been similar, even if attenuated, to those obtained for the central executive (*Verbal Trails*) group in both feedback conditions. Verbal trails could not be considered simply a harder task, as neither floor nor ceiling effects were noted in the performance of the *Verbal Trails* group.

The difference in the pattern of results between the *Visual Interference* and *Spatial Tapping* groups also provides support for the fractionation of the visuospatial sketchpad. Consistent with Logie's (1995) view of visuospatial working memory the secondary task of spatial tapping, which involved movement, disrupted performance in both feedback conditions whereas the visual interference task which required the temporary storage of a static geometrical design only disrupted performance in the no visual feedback condition.

The quality of the errors made was also of interest in this experiment. Contrary to what was expected, overall a higher percentage of perseverative errors were made in the no visual feedback condition. Cinan and Tanör (2002) found that when participants were unable to see the previous response cards they were less likely to match the present response card to the previous response card. However, in their study participants sorted to one-dimensional key cards whereas in the present experiment three-dimensional key cards were used. Therefore, when participants were given negative verbal feedback with no visual assistance as to their previous response (no visual feedback) the demand on working memory capacity would have been greater. In the present study the percentage of perseverative errors also increased significantly in both feedback conditions with the addition of the secondary tasks. This suggests that the number of perseverative errors was influenced by the working memory manipulations. As the percentage of perseverative errors made never exceeded 40 % and given the fact that after negative verbal feedback there is a one in three chance of a perseverative error being scored, it seems reasonable to assume that in this nonclinical sample these errors reflect working memory ability, as do random errors, rather than a perseverative tendency.

There were some limitations in this study that require discussion. One of the limitations was that the secondary visual interference task could be verbalised. If the phonological loop was required for the maintenance of the sorting rules then, in the *Visual Interference* group, poorer performance in the no visual feedback condition could have been due to a disruption of the phonological loop, as well as the visual store. The significant effect of articulatory suppression in the visual feedback condition only, suggests that the phonological loop is involved to a greater extent when visual feedback is present. Therefore, as the secondary visual interference task had less effect on card sorting test performance when visual feedback was present in *Visual Interference* group, this explanation for the significant feedback x interference interaction in the *Visual Interference* group is unlikely.

The verbal trails task could also be thought to recruit the phonological loop. Nonetheless, Baddeley and colleagues (Baddeley, 1996) showed that the verbal trails task was as effective at disrupting the central executive as random letter generation, a task substantiated as interfering with central executive performance (see section 4.2), whereas simply reciting the alphabet or numbers was not.

Another limitation of the study was that the accuracy of the secondary task performances were not recorded which means a trade-off in performance may have been operating. However, a trade-off in performance was not found in the pilot studies and in this study the pace of performance for all secondary tasks was controlled and monitored.

In the majority of previous studies investigating the working memory-card sorting test relationship, in which correlational, regression, or factor analyses were employed (Doiseau & Isingrini, 2005; Gold et al., 1997; Gooding & Tallent, 2002; Tallent & Gooding, 1999), only one working memory task was administered to represent either auditory (Letter Number Span; Digit Span Backwards and/or Forwards; updating memory task) or spatial (Spatial Delayed Response Task) working memory. In studies that utilised the dual-task paradigm (Cinan & Tanör, 2002; Dunbar & Sussman, 1995) the secondary tasks chosen were designed to interfere with either the phonological loop or central executive. The design of the present study is the first in which the contribution made by both slave systems and the central executive has been incorporated within the one study. This study design provides a more comprehensive understanding of the role of working memory in card sorting test performance. In addition, the effect of visual feedback from previous response cards on overall performance and in relation to the individual working memory components was explored.

The present results have not only supported previous findings but have identified a role for the visual store not previously examined and have indicated that the contribution made by the individual components is not equivalent. In summary, the current findings indicate that all components of working memory are involved in card sorting test performance. Moreover, the degree of contribution made by the phonological loop and visual store appears to be dependent on the presence or absence of visual feedback. When visual feedback is present, as in the WCST, there is an indication of greater involvement of the phonological loop although this component is also required when visual feedback is absent. However, the visual store which appears to be significantly involved when visual feedback is absent does not seem to be required in the presence of visual feedback. In many research projects investigating WCST performance the provision of visual feedback appears to have been overlooked. As a result, poor performance may have been erroneously attributed to alternative processes or to the other working memory components. Therefore, it would be prudent for this variable to be considered in the design of future studies.

So far the experiments reported in this thesis have explored the working memory-card sorting test relationship in nonclinical populations. In the first two experiments the relationship was examined by comparing the performance on two card sorting tests of individuals with significantly different working memory abilities, as assessed by tasks representing all modalities. The results obtained were further explored in the present experiment by manipulating participants' working memory ability by the introduction of secondary tasks designed to interfere with specific working memory components. Although the present findings have been informative, ultimately the aim of any research into card sorting test performance is to better understand the impaired cognitive processes underlying poor performance in clinical populations. Research involving patients with schizophrenia has been quite extensive but has mainly focussed on only one aspect or component of working memory. In studies of the WCST performance of patients with frontal and nonfrontal lobe lesions, the results have been interpreted with respect to working memory but none have directly examined the relationship between working memory and WCST performance.

When Dunbar and Sussman (1995) administered the WCST to a patient with a left temporoparietal lesion and conduction aphasia the patient obtained zero categories and 94 perseverative errors. His main deficit had been determined previously as a pure case of an articulatory rehearsal deficit. A. Hartman et al. (1992) found a significant positive correlation between dual-task performance and WCST measures for severe head-injured patients with frontal lobe dysfunction. However, no group studies have been conducted that directly investigate the role of multiple aspects of working memory in card sorting in a clinical population. As the findings to date suggested that the phonological loop and visual store differentially contribute to successful card sorting, the final experiment focussed on the card sorting test performance of head-injured patients displaying impaired working memory ability in the auditory or visual modality.

CHAPTER 10

Experiment 4: Card Sorting Test Performance in a Closed Head-Injured Population

The focus of this thesis has been on determining the contribution of the different components of Baddeley's (1986, 1998, 2001) working memory model in card sorting test performance. It has been hypothesised that the contribution of the different components is differentially affected by alterations in the presentation of visual aspects of the test, with greater involvement of the phonological loop in the presence of visual feedback and involvement of the visual store only when visual feedback is absent.

The hypotheses, however, have been derived from the results of experiments involving university students in which a reduction in working memory ability was manipulated by experimental design (e.g., the use of concurrent secondary tasks in Experiment 3). As previous research has shown, hypotheses generated from results found in nonclinical populations and supported by experiments involving clinical populations have provided insight into the impaired processes in a range of clinical disorders (e.g., Alzheimer's Disease, unilateral spatial neglect, schizophrenia), as well as a better understanding of patient behaviours (e.g., Environmental Dependency, Dysexecutive Syndrome). Therefore, further investigation of the present hypotheses in a clinical population differentially impaired on tests of auditory and visual working memory is required and will be the focus of Experiment 4. In addition, examining the relationship between working memory and the various card sorting test index scores could provide a finer appreciation of performance outcome and potentially contribute to the design of appropriate rehabilitation programmes (Greve et al., 2002).

Perseverative errors are typically regarded as indicators of frontal lobe dysfunction and, together with the categories achieved score, have been the primary dependent variable considered in many research studies (see Barceló, 2001). However, some researchers have shown other measures, proposed as representing a variety of cognitive processes, to be of equal importance in interpreting card sorting test performance (Barceló, 1999; Barceló & Knight, 2002; Hartman et al., 2001, 2003). Gold et al. (1997) found that performance on an auditory working memory task predicted the categories achieved score whereas performance on the executive tasks of trail making and verbal fluency were the most significant predictors of the percentage of perseverative errors. Likewise, Everett et al. (2001) and Perry et al. (2001) suggested perseverative errors reflect cognitive inflexibility and nonperseverative errors reflect working memory deficits. Barceló (1999) has been even more specific in suggesting that random errors, as distinct from the combination of efficient and random errors (nonperseverative errors), represent distractions related to working memory due to an inadequate ability to inhibit interfering stimuli. Barceló and Knight (2002) found that the patients with frontal lobe lesions in their study rarely exhibited extreme perseverative tendencies (stuck-in-set score) and committed more random than perseverative errors in 52% of the defined categories. They also found that patient and control groups made significantly more random errors in the early trials than in the late trials of a category series whereas there was no significant difference between early and late trials on the perseverative error score. In previous studies Barceló and colleagues (Barceló, 1999; Barceló, Periáñez, & Knight, 2002) showed that perseverative and random errors represent different prefrontal neural networks. The loss of set/failure to maintain set score has also been proposed to reflect attention, memory, and/or impulsivity (Greve et al., 2002), and a high number of failure to establish set scores has been suggested as reflecting difficulties in problem solving and conceptualisation.

Mild closed head injured patients typically present with attentional deficits, heightened distractibility, an inability to do more than one thing at the same time, and verbal retrieval deficits. These symptoms, primarily due to diffuse axonal injury, can occur without loss of consciousness or posttraumatic amnesia and have been found to still be evident three-months post-injury (Lezak et al., 2004). Unless language areas are involved most mild head-injured patients display no deficits on tests that measure long-term memory and learning ability. In a clinical setting the concept of impairment or dysfunction is determined not only by test cut-off scores (i.e., a statistically derived score that differentiates impaired from non-impaired) but also in relation to a patient's estimated premorbid level of functioning. However in the interests of consistency, for this experiment cut-off scores only were used to determine impaired/dysfunctional performance.

Therefore, the aims of this final experiment were a) to further explore the dissociations found in Experiment 3 regarding the phonological loop and the visual store, with respect to the presence or absence of visual feedback and b) to examine the relationship between working memory impairment and the card sorting test index scores. In line with the findings in Experiment 3 it was hypothesised that

- if the visual store is only required when visual feedback is absent, then patients with impaired visual working memory should commit more errors and achieve fewer categories in the no visual feedback than in the visual feedback condition of the card sorting test.
- if involvement of the phonological loop is greater when visual feedback is present, to assist with inhibitory control, then patients with impaired auditory working memory should commit more errors and achieve fewer categories in the visual feedback than in the no visual feedback condition.

Furthermore, based on previous research into the relationship between cognitive processes and the card sorting test index scores

- if random errors reflect working memory deficits then the working memory dysfunction groups would be expected to make more random errors than either the control or executive dysfunction group.
- if cognitive inflexibility underlies perseverative errors and is a reflection of an aspect of frontal lobe dysfunction, then a higher percentage of perseverative errors would be expected for the executive dysfunction group than for the other three groups.

Method

Participants

Participants were selected from the Neurotrauma Register, a joint research project conducted by the University of Tasmania and Royal Hobart

Hospital. All participants had suffered a closed head injury, had a Full Scale IQ of at least 75, and were selected on the basis of their initial neuropsychological assessment, which was conducted within the first two weeks post-injury. Scores on tests of executive function described in Chapter 2 (Brixton Spatial Anticipation Test, Trail Making Test-B, FAS), visual working memory (Visual Patterns Test), and auditory working memory (Forward minus Backward string of Digit Span) provided the criteria for selection. The inclusion criteria for each experimental group was as follows:

Group 1 – Head-injured controls (HC)

- No impairment on any measure of executive function or working memory.

Group 2 - Executive dysfunction only (Ed)

- < 25th percentile on 2 out of 3 executive function tests
- no impairment on either working memory measures

Group 3 - Executive plus auditory working memory dysfunction (Ad)

- < 25th percentile on 2 out 3 executive function tests
- Digit Span Forward minus Backward string = >2
- Score above 28th percentile (>level 8) on the Visual Patterns Test

Group 4 - Executive plus visual working memory dysfunction (Vd)

- < 25th percentile on 2 out 3 executive function tests
- < 28th percentile ($\leq$ level 8) on the Visual Patterns Test
- Digit Span Forward minus Backward string = < 3

Of the 447 patients who completed the baseline assessment 222 were either lost to follow-up or were unavailable for testing within four weeks post-baseline. Of the remaining 225, only 59 patients met the inclusion criteria. As shown in Table 10.1 the final sample consisted of 16 patients in the head-injured control group, 20 in the executive dysfunction group, 17 in the visual dysfunction group, and 6 in the auditory dysfunction group.

Table 10.1
Number of males and females in each group

	Head-injured control	Executive dysfunction	Auditory dysfunction	Visual dysfunction
Males	10	15	6	14
Females	6	5	0	3

Overall, the ratio for males to females was 3:1, which is not atypical for a head-injured population (e.g., Milders, 1998; Rey et al., 2001; Zec et al., 2001). The study was approved by the Human Research Ethics Committee (Tasmania) Network and written informed consent was obtained from all participants (Appendix E).

Materials

Card sorting: The modified card-sorting test used in Experiment 3.

Scores were also obtained from the Neurotrauma Resister baseline neuropsychological assessment for the following tests:

Injury severity: Posttraumatic amnesia (PTA: Russell & Smith, 1961) and subsequent simplification; up to one day = mild; one day to one week = moderate (Kay, Harrington, & Adams, 1993).

Estimated IQ: National Adult Reading Test (NART: Nelson & Willison, 1991) or the Vocabulary subtest of the WAIS-III (Wechsler, 1997a) in the presence of a specific learning disability.

Executive function: Brixton Spatial Anticipation Test (Burgess & Shallice, 1997)

Controlled Oral Word Association Test (FAS: Benton, 1968)

Trail Making Test-B (Reitan & Wolfson, 1985)

Auditory working memory: Digit Span (Wechsler, 1997a) Forward minus Backward string as recommended by Lezak et al. (2004).

Visual working memory: Visual Patterns Test (Della Sala et al., 1999)

Information Processing: Information Processing-Form 1 (Coughlan & Hollows, 1985)

Procedure

Participants completed the two versions (visual feedback; no visual feedback) of the modified card-sorting test as described in Experiment 3 within one month of their baseline neuropsychological assessment. This time frame coincided with either their two-week or one-month post-injury follow-up appointment with the Neurotrauma Register. The order of presentation of the two versions was counterbalanced within each group. An interval of 20-30 min between administrations of the two card-sorting tests was filled by the completion of cognitive tests for the Neurotrauma Register.

Design and Data Analysis

A 4 [group: head-injured control, executive dysfunction, auditory dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) mixed factorial design was used with the within-subjects factor being feedback. The dependent variables were number of categories achieved, number of total errors, number of random errors, percentage of perseverative errors, loss of set, and failure to establish set. Loss of set was scored if an incorrect response was made after two or more consecutive correct responses within the same category. Failure to establish set was scored if the participant failed to respond correctly on any trial of the category.

Means and standard deviations were calculated and analysed using repeated measures analysis of variance with an alpha significance level of .05. Chi-square analysis was used to evaluate frequencies in each group and Pearson's product-moment correlations were used to assess the relationship between variables.

Results

One way ANOVAs for the demographic variables (see Table 10.2) showed no significant difference between groups for age, $F(3,55)=0.76$, $p=.52$, but there was a significant difference for Full Scale IQ, $F(3,55)=5.37$, $p<.01$. The Full Scale IQ for head-injured controls was significantly higher than for the executive dysfunction, $F(1,35)=8.05$, $p<.01$, and visual dysfunction ($F(1,30)=13.19$, $p=.001$ groups which were not significantly different from each other. The auditory dysfunction group was not significantly different to any other group.

Table 10.2
Means (standard deviations) for demographic variables.

	HC n=16	Ed n=20	Ad n=6	Vd n=17
Age	35.00 (18.2)	30.90 (14.8)	24.50 (8.6)	32.12 (12.6)
Full Scale IQ	108.08 (9.0)	98.75 (10.3)	106.00 (10.6)	93.07 (13.6)

HC = Head-injured controls; Ed = Executive dysfunction group; Ad = Auditory dysfunction group; Vd = Visual dysfunction group.

As can be seen in Table 10.3 there was a significant difference between the groups on all cognitive variables except for information processing error percentile. One-way ANOVAs confirmed that the selection criteria for each group were appropriate. Head-injured controls obtained significantly higher scores on the executive function tests of the Brixton, Trail Making Test, and FAS than the executive dysfunction group, $F(1,35) = 11.86$, 186.92, and 26.76 respectively, $ps<.01$, and the visual dysfunction group, $F(1,32) = 22.87$, 160.68, and 114.41 respectively, $ps<.001$, and significantly higher scores on the Trail Making Test and FAS than the auditory dysfunction group, $F(1,21) = 58.11$ and 39.63 respectively, $ps<.001$. The three dysfunction groups (Ed, Vd, Ad) groups were not significantly different from each other on the executive tasks. The auditory dysfunction group had significantly higher Digit Span F-B scores than the head-injured control, $F(1,21)=22.37$, $p<.001$, executive dysfunction, $F(1,25)=35.88$, $p<.001$, and visual

Table 10.3

Means (standard deviations) for the cognitive tests for each group and the F- and p-values for the one-way ANOVAs for each cognitive test.

	HC	Ed	Ad	Vd	F and p-values
Digit Span Forward-Backward string	1.44 (0.7)	1.40 (0.6)	3.17 (0.4)	1.18 (1.0)	$F(3,58)=9.41, p<.001$
Visual Patterns Test (percentile)	74.31 (20.0)	65.55 (17.8)	59.83 (10.7)	14.82 (10.6)	$F(3,58)=44.92, p<.001$
Brixton (percentile)	79.25 (14.9)	52.45 (28.0)	55.80 (40.1)	41.88 (27.6)	$F(3,58)=5.80, p<.01$
Trail Making Test (percentile)	71.37 (19.6)	4.50 (8.7)	7.00 (9.3)	3.82 (9.5)	$F(3,58)=104.54, p<.001$
FAS (percentile)	51.87 (16.0)	18.05 (21.8)	8.67 (7.0)	6.41 (6.8)	$F(3,58)=25.98, p<.001$
Information Processing (percentiles)					
total	72.47 (27.6)	37.00 (27.6)	50.83 (25.0)	23.96 (20.8)	$F(3,57)=10.33, p<.001$
error	67.40 (19.5)	56.16 (27.8)	66.00 (13.7)	50.59 (28.0)	*ns*
speed	70.07 (24.3)	41.05 (27.7)	67.48 (26.4)	30.32 (24.7)	$F(3,57)=7.89, p<.001$
adjusted	72.60 (29.2)	37.95 (27.7)	50.67 (24.5)	24.25 (21.0)	$F(3,57)=9.75, p<.001$

HC = Head-injured controls; Ed = Executive dysfunction group; Ad = Auditory dysfunction group; Vd = Visual dysfunction group dysfunction, $F(1,22)=21.31$, $p<.001$, groups which were not significantly different from each other. The visual dysfunction group had significantly lower scores on the Visual Patterns Test than the head-injured control, $F(1,32)=115.36$, $p<.001$, executive dysfunction, $F(1,36)=105.29$, $p<.001$, and auditory dysfunction, $F(1,22)=79.16$, $p<.001$, groups which were not significantly different from each other.

One-way ANOVAs on the Information Processing total, speed, and adjusted scores indicated that the head-injured control group had significantly higher scores than the executive dysfunction, $F(1,34) = 14.13$, 10.41, and 12.76 respectively, $p<.01$, and visual dysfunction, $F(1,31) = 31.90$, 20.90, and 29.36 respectively, $p<.001$, groups which were not significantly different from each other. The auditory dysfunction group had significantly higher Information Processing total, speed and adjusted scores than the visual dysfunction group, $F(1,22) = 6.66$, 9.66, and 6.43 respectively, $p<.05$, but was not significantly different from the head-injured control or executive dysfunction groups on these variables.

The participant number for the auditory dysfunction group was particularly small (n=6). As a chi-square analysis (Appendix E) indicated that this group was close to being significantly smaller than the other three groups (χ^2 (3, N=59)=7.50, p=.06), it was omitted from the main analysis and will be presented separately.

Injury severity for all patients in the head-injured control group was classified as mild. In the executive dysfunction group the ratio of mild to moderate severity was 6:14 and for the visual dysfunction group 9:8. A chi-square analysis showed no significant difference between the executive and visual dysfunction groups in the ratio of mild to moderate severity. One-way ANOVAs indicated that patients whose severity was classified as mild scored significantly higher on the Trail Making Test, $F(1,51)=14.23, p<.001$, and FAS, $F(1,51)=6.41, p=.01$, than patients classified as moderate. However, there were no significant differences on any other variable (Appendix E).

Means and standard deviations for the card sorting test variables for all four groups are reported in Table 10.4 and were screened for normality. Total errors, random errors, loss of set, and failure to establish set were found to be positively skewed (Appendix E). Consequently, logarithm transformations, which produced the best fit, were used for all analyses and the F-values reported for total errors, random errors, loss of set, and failure to establish set are for the transformed variables. As there was a significant difference between the groups for FSIQ, analyses of covariance were used for all analyses.

Categories achieved

A 3 [group: head-injured controls, executive dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) ANCOVA showed a significant main effect for group only, $F(2,47)=9.78, p<.001$.(Figure 10.1). One-way ANCOVAs showed that the visual dysfunction group achieved significantly fewer categories than the head-injured controls, $F(1,28)=26.18, p<.001$, and executive dysfunction group, $F(1,32)=6.06, p=.02$. The executive dysfunction group also achieved fewer categories than the head-injured controls, which verged on significance, $F(1,33)=4.06, p=.05$.

Table 10.4

Means (standard deviations) for the card sorting test variables for each group with and without visual feedback

		HC	Ed	Ad	Vd
Categories achieved					
	visual feedback	6.75 (1.4)	5.90 (2.1)	5.67 (1.7)	4.12 (2.1)
	no visual feedback	6.62 (1.2)	5.05 (2.1)	5.00 (1.2)	3.41 (2.1)
Total errors					
	visual feedback	2.44 (2.9)	4.00 (5.0)	4.83 (4.6)	9.53 (5.8)
	no visual feedback	2.19 (1.9)	6.60 (7.2)	6.00 (3.1)	11.59 (7.1)
Random errors					
	visual feedback	1.56 (2.0)	2.75 (3.1)	3.00 (3.2)	5.71 (4.1)
	no visual feedback	1.50 (1.7)	4.10 (4.3)	3.67 (3.4)	6.65 (3.9)
% perseverative errors					
	visual feedback	20.13 (25.9)	18.20 (21.3)	29.17 (24.9)	36.47 (23.3)
	no visual feedback	21.06 (31.9)	34.15 (26.7)	52.17 (32.3)	36.41 (20.8)
Loss of set					
	visual feedback	0.31 (0.4)	0.25 (0.4)	0.50 (0.8)	0.53 (0.8)
	no visual feedback	0.44 (0.8)	0.65 (0.8)	0.33 (0.5)	0.88 (0.9)
Failure to establish set					
	visual feedback	0.38 (0.6)	0.65 (0.8)	0.50 (0.5)	1.76 (1.1)
	no visual feedback	0.25 (0.4)	0.90 (1.2)	0.83 (0.9)	1.94 (1.6)

HC = Head-injured controls; Ed = Executive dysfunction group; Ad = Auditory dysfunction group; Vd = Visual dysfunction group.

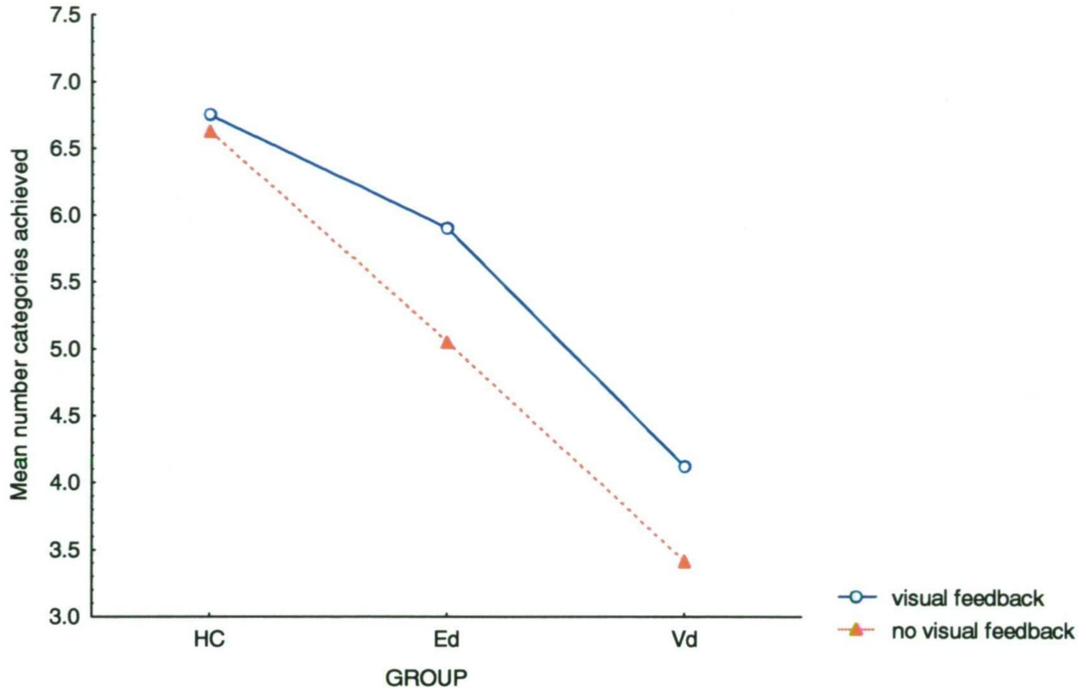

Figure 10.1. Mean number of categories achieved, with and without visual feedback, for the head-injured control (HC), executive dysfunction (Ed), and visual dysfunction (Vd) groups.

Total errors (logarithm transformed)

A 3 [group: head-injured controls, executive dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) ANCOVA showed a significant main effect for group only, $F(2,47)=12.63$, $p<.001$ (Figure 10.2). One-way ANCOVAs indicated that the visual dysfunction group scored significantly more errors than the head-injured controls, $F(1,28)=31.04$, $p<.001$, and executive dysfunction group, $F(1,32)=9.93$, $p=.01$. The executive dysfunction group also scored more errors than the head-injured controls, which verged on significance, $F(1,33)=4.03$, $p=.05$.

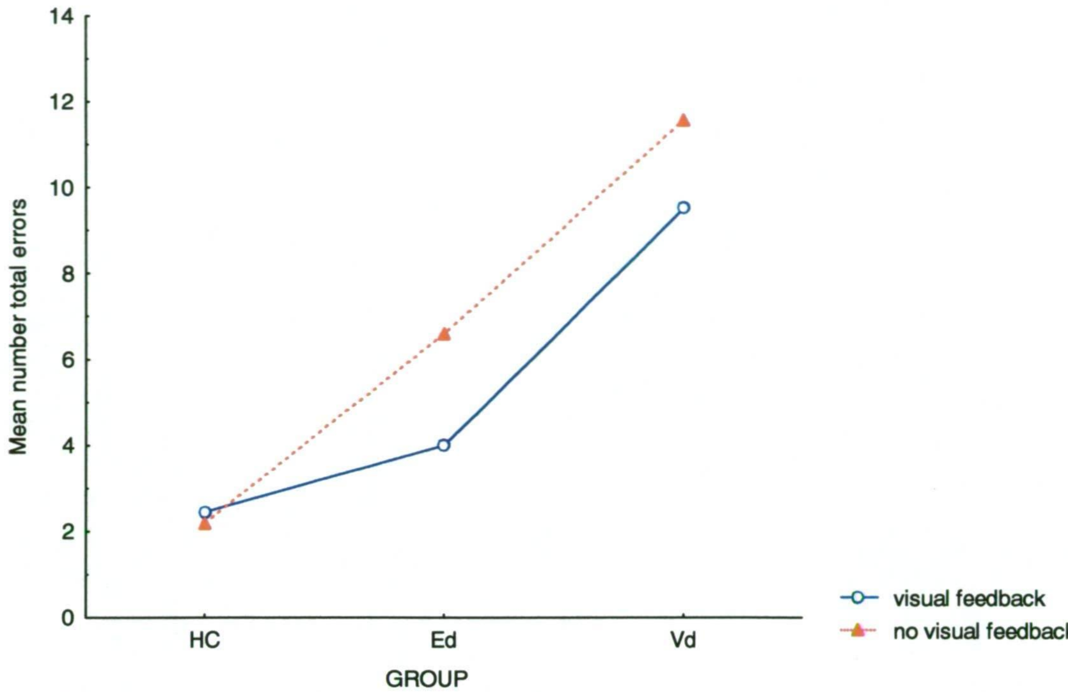

Figure 10.2. Mean number of total errors, with and without visual feedback, for the head-injured control (HC), executive dysfunction (Ed), and visual dysfunction (Vd) groups.

Random errors (logarithm transformed)

A 3 [group: head-injured controls, executive dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) ANCOVA showed a significant main effect for group only, $F(2,47)=11.30$, $p<.001$ (Figure 10.3). One-way ANCOVAs indicated that the visual dysfunction group made significantly more random errors than the head-injured control, $F(1,28)=27.74$, $p<.001$, and executive dysfunction, $F(1,32)=8.04$, $p<.01$, groups. The executive dysfunction group also made more random errors than the head-injured controls, which verged on significance, $F(1,33)=4.06$, $p=.05$.

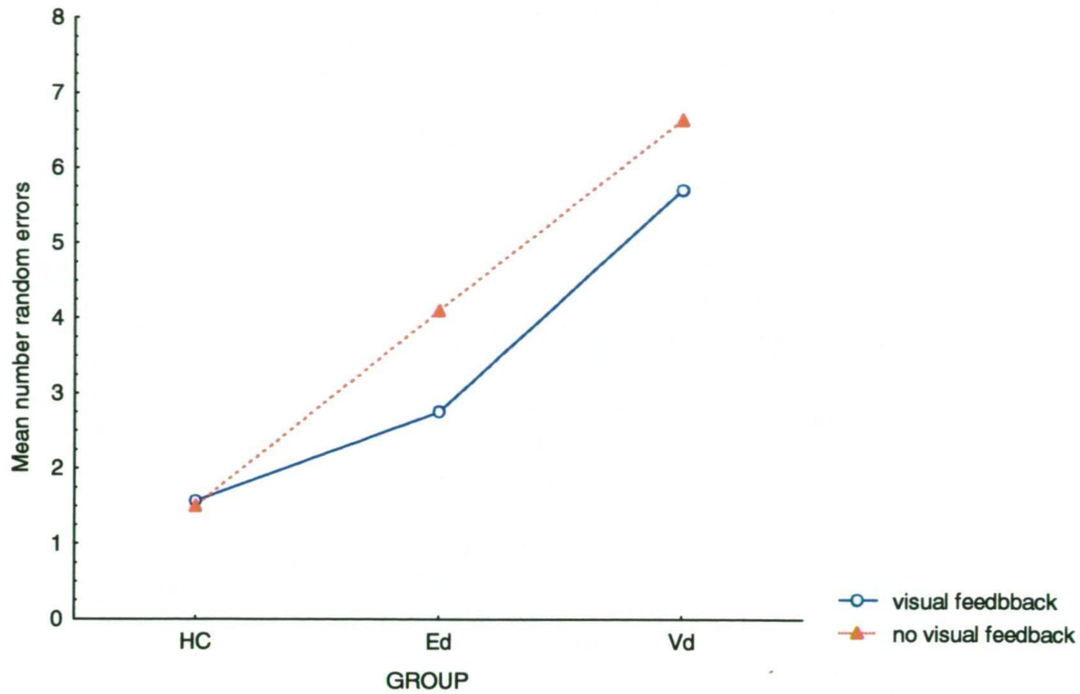

Figure 10.3. Mean number of random errors, with and without visual feedback, for the head-injured control (HC), executive dysfunction (Ed), and visual dysfunction (Vd) groups.

Percentage perseverative errors

A 3 [group: head-injured controls, executive dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) ANCOVA showed a significant main effect for feedback, $F(1,47)=4.53$, $p=.04$; a significant feedback x FSIQ interaction, $F(1,47)=5.09$, $p=.03$; and a trend towards a significant feedback x group interaction, $F(2,47)=2.71$, $p=.08$ (Figure 10.4). One-way repeated measures ANOVAs showed no significant difference between feedback conditions for the head-injured controls, $F(1,15)=.01$, $p=.91$ or the visual dysfunction group, $F(1,16)=.01$, $p=.99$. However, the executive dysfunction group made a significantly higher percentage of perseverative errors in the no visual feedback than visual feedback condition, $F(1,19)=8.81$, $p=.01$. Further analyses between the dysfunction groups showed no significant difference between the groups when visual feedback was absent, $F(1,35)=.08$, $p=.78$, but when visual feedback was present the executive dysfunction group made a significantly lower percentage of perseverative errors than the visual dysfunction group, $F(1,35)=6.17$, $p=.02$.

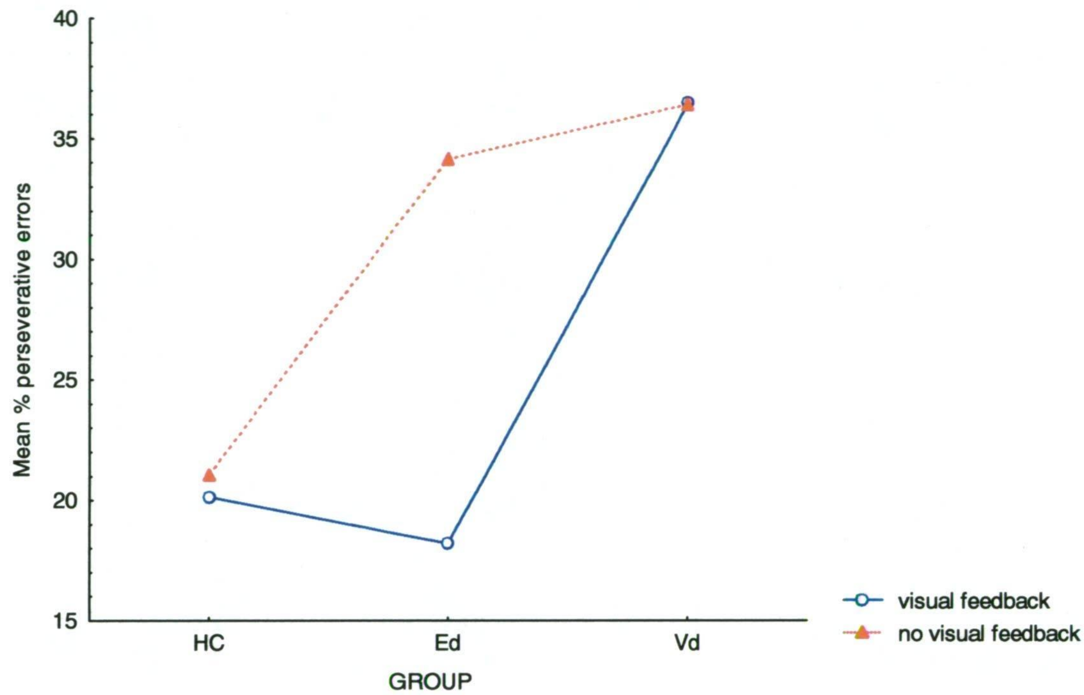

Figure 10.4. Mean percentage of perseverative errors, with and without visual feedback, for the head-injured control (HC), executive dysfunction (Ed), and visual dysfunction (Vd) groups.

Loss of set (logarithm transformed)

A 3 [group: head-injured controls, executive dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) ANCOVA showed a trend towards a significant main effect for group, $F(2,47)=2.77$, $p=.07$. One-way ANCOVAs indicated that the visual dysfunction group made a higher number of loss of set than both the head-injured controls, $F(1,28)=4.35$, $p=.046$, and the executive dysfunction group, $F(1,32)=4.58$, $p=.04$, which were not significantly different from each other, $F(1,33)=.05$, $p=.83$.

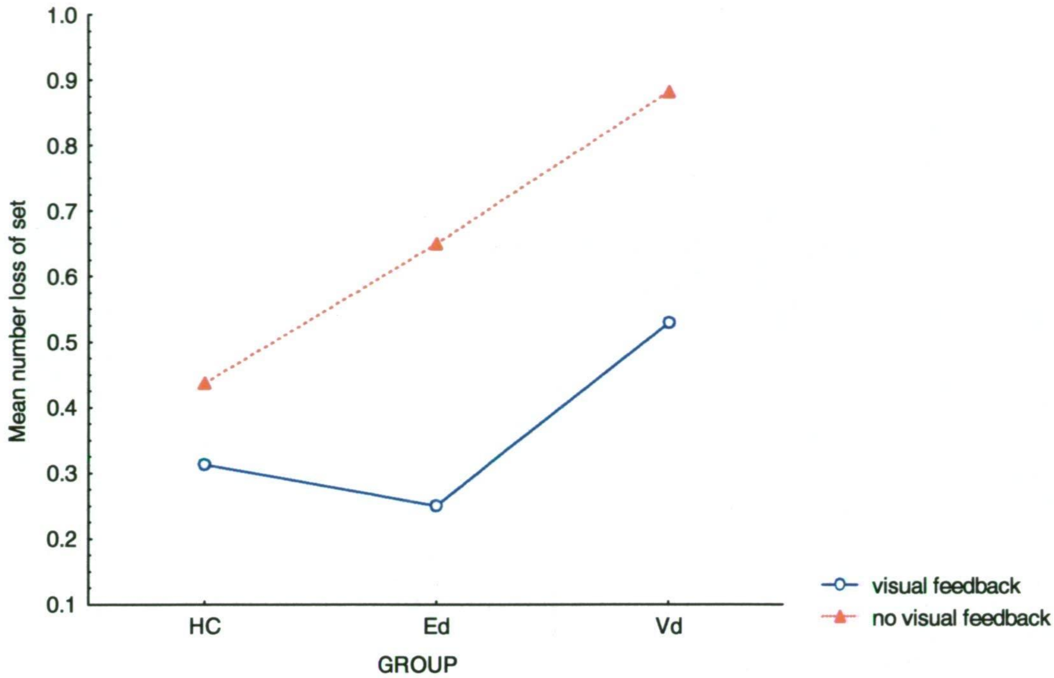

Figure 10.5. Mean number of loss of set, with and without visual feedback, for the head-injured control (HC), executive dysfunction (Ed), and visual dysfunction (Vd) groups.

Failure to establish set (logarithm transformed)

A 3 [group: head-injured controls, executive dysfunction, visual dysfunction] x 2 (feedback: visual, no visual) ANCOVA showed a significant main effect for group only, $F(2,47)=10.84$, $p<.001$ (Figure 10.6). One-way ANOVAs indicated that the visual dysfunction group scored significantly more failure to establish set scores than the head-injured controls, $F(1,28)=24.77$, $p<.001$, and executive dysfunction group, $F(1,32)=7.94$, $p=.01$. There was also a trend for the executive dysfunction group to score significantly more failure to establish set scores than the head-injured controls, $F(1,33)=3.64$, $p=.07$.

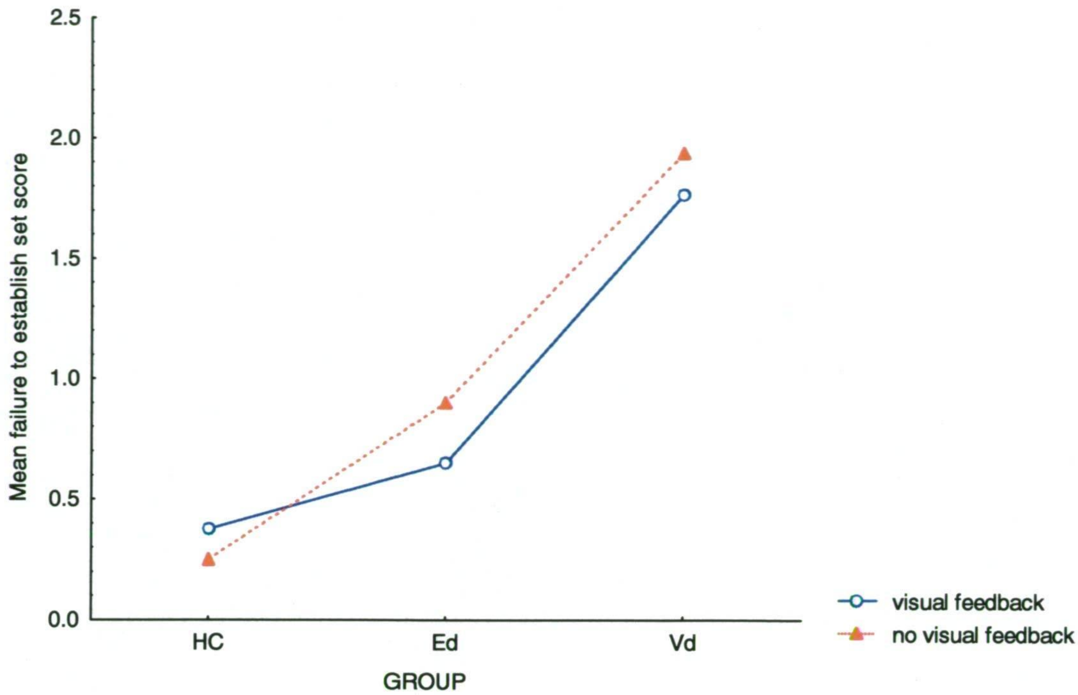

Figure 10.6. Mean number of failure to establish set scores, with and without visual feedback, for the head-injured control (HC), executive dysfunction (Ed), and visual dysfunction (Vd) groups.

Auditory dysfunction group analyses

One-way ANCOVAs indicated that the auditory dysfunction group achieved significantly fewer categories and more total errors, $F(1,18)=6.23$ and 5.12, $p<.05$ respectively, than the head-injured controls. There was also a trend for the auditory dysfunction group to make fewer random errors, $F(1,17)= 4.04$, $p=.06$, and fewer failure to establish set scores, $F(1,17)= 3.68$, $p=.07$, than the visual dysfunction group.

Although the auditory dysfunction group made a higher percentage of perseverative errors than the head-injured controls, $F(1,18)=4.73$, $p=.04$, there was no significant difference between the auditory and the other two dysfunction groups. There was also no significant difference between the auditory and executive dysfunction groups on any dependent variable.

Correlational analyses

Table 10.5 displays the correlations between the cognitive tasks and card sorting test variables. As can be seen the highest correlations ranging from .43 to .57 were between the Visual Patterns Test percentile score and the card sorting test variables of categories achieved, total errors, random errors, and failure to establish set. The executive function tasks variably correlated with these card sorting test measures. To establish whether the correlations for the Visual Patterns Test were stronger than those for the executive tasks, partial correlations were performed. As can be seen in Table 10.6 when the Visual Patterns Test was controlled for the correlations between the executive tasks and the card sorting test variables of categories achieved, total errors, random errors, and failure to establish set were reduced. This suggests that visual working memory plays a major role in determining card sorting test errors. As the range of scores for the Digit Span F-B string was small (4) with only six participants scoring above 2 correlations were not computed for this variable.

Table 10.5

Correlations between the cognitive tasks and card sorting test variables with (VF) and without (NVF) visual feedback.

	Categories		Total errors		Random errors		% perseverative errors		Loss of set		Failure to establish set	
	VF	NVF	VF	NVF	VF	NVF	VF	NVF	VF	NVF	VF	NVF
Visual Patterns Test percentile	.51*	.51*	-.56*	-.49*	-.51*	-.43*	-.24	-.08	-.12	-.12	-.57*	-.48*
Brixton percentile	.19	.44*	-.21	-.44*	-.19	-.39*	-.09	-.13	.08	-.16	-.19	-.35*
Trail Making Test percentile	.31	.40*	-.29	-.34*	-.26	-.33	-.13	-.14	-.06	-.08	-.25	-.31
FAS percentile	.34*	.36*	-.34*	-.31	-.29	-.29	-.21	-.13	-.16	-.13	-.23	-.29
Information Processing percentiles												
total	.33*	.31	-.37*	-.31	-.33*	-.29	-.22	.02	.04	-.08	-.41*	-.31
errors	.04	.25	-.04	-.22	.05	-.16	-.12	-.10	.22	.01	-.12	-.14
speed	.23	.38*	-.27	-.34*	-.24	-.29	-.19	-.11	-.10	.02	-.25	-.37*
adjusted	.34*	.32	-.38*	-.32	-.34*	-.30	-.22	.04	.03	-.10	-.41*	-.32

*p<.01

Table 10.6

Partial correlations between the executive function tasks and card sorting test variables with (VF) and without (NVF) visual feedback, controlling for the Visual Patterns Test.

	Categories		Total errors		Random errors		Failure to establish set	
	VF	NVF	VF	NVF	VF	NVF	VF	NVF
Brixton percentile	.05	.36*	-.06	-.35*	-.06	-.31	-.28	-.04
Trail Making Test percentile	.09	.22	-.04	-.15	-.02	-.16	-.11	-.02
FAS Percentile	.08	.11	-.05	-.06	-.01	-.07	-.03	.08

*p<.01

Discussion

The main purpose of this final experiment was to investigate hypotheses involving the phonological loop and the visual store, and to explore the relationship between working memory and the card sorting test measures. Unfortunately, the number of participants to meet criteria for the auditory dysfunction group was too small to include in the main analyses but will be discussed later in this section.

Contrary to expectations patients in the visual dysfunction group did not make significantly more errors in the no visual feedback condition. Therefore, the hypothesis that the visual store is only involved in card sorting in the absence of visual feedback was not supported. However, a significant main effect for feedback with a trend towards a significant feedback x group interaction was found for the percentage of perseverative errors. The implications of this result are also discussed later in this section.

In the present experiment patients who met the inclusion criteria for the visual dysfunction group were also impaired on executive tasks. The majority of patients in all dysfunction groups scored below the 1st percentile on the Trail Making Test with only two patients scoring above the 25th percentile. The Trail Making Test correlates highly with the WCST (Lezak et al., 2004) and relates to the ability to handle more than one stimulus at a time and to make cognitive shifts; processes associated with the central executive (Baddeley, 1996). As evidenced in Experiment 3, an increase in memory and processing load associated with the removal of visual feedback resulted in significantly more errors being committed by all groups. One possible explanation for the overall lack of a feedback effect in this experiment maybe that if central executive capacity is already impaired to threshold then the effect of additional memory and/or processing load is negligible.

Alternatively, impaired performance on the Visual Patterns Test may have reflected not only impaired visual but also spatial working memory. Although the Visual Patterns Test has been shown to measure visual storage capacity the task is not devoid of a spatial component (Della Sala et al., 1999). A spatial task, such as the Corsi Blocks, was not included in the baseline neuropsychological assessment; therefore the possibility of co-occurring impaired spatial working memory cannot be ruled out. In Experiment 3 no differential effect of feedback occurred with the addition of a secondary spatial task. As discussed in Chapter 9 this suggests that the contribution of spatial working memory to card sorting is the same irrespective of whether visual feedback from previous response cards is present or absent. If patients in the visual dysfunction group were impaired in both visual and spatial working memory this could also account for the lack of a feedback effect.

As hypothesised the significant role of working memory in card sorting test performance was demonstrated by the higher number of random errors made by the visual dysfunction group compared to the head-injured controls and executive dysfunction group. Whereas perseverative errors reflect an inability to shift from a previous response pattern, random errors reflect an inability to maintain, monitor, and integrate information from previous sorts and verbal feedback (Barceló & Knight, 2002). Barceló and colleagues (Barceló, 1999; Barceló & Knight, 2002) also proposed that random errors relate to a susceptibility to distraction and interference evident in the late trials of a category series. In the present experiment, although both dysfunction groups made significantly more errors in the early trials of a category than the head-injured controls, only the visual dysfunction group made significantly more errors in the late trials.

Contrary to what was expected there was no significant difference between the dysfunction groups on the percentage of perseverative errors, which was approximately one third or less for all groups. This would suggest that cognitive inflexibility might not have been the primary reason for perseverative errors in this sample. No participant displayed extreme perseverative tendencies (i.e., a category of only perseverative errors). As the definition for a perseverative error was related to the immediately preceding response rather than to a series of positively reinforced responses, as defined in the original WCST, the errors may have represented repetition due to attentional deficits rather than an inability to terminate a set pattern of response. Repetitions are more likely to occur in patients with diffusely impaired brain functioning (Lezak et al., 2004). As all patients had suffered a closed head injury with the severity level ranging from mild to moderate, it seems more likely that the perseverative errors made were due to an inability to keep track of previous responses. Although the visual dysfunction group made the same percentage of perseverative errors as the executive dysfunction group, they made significantly more total errors. It may be that the extent, as distinct from the severity, of these patients' diffuse damage was greater, affecting the functions of the visuospatial sketchpad as well as those of the central executive.

Even though there was no significant difference between the groups in the percentage of perseverative errors made overall, there was a significant group x feedback interaction. Further analyses showed no significant difference in the dysfunction groups when visual feedback was absent. However, when visual feedback was present the executive dysfunction group made a significantly lower percentage of perseverative errors than the visual dysfunction group. This result suggests that when the working memory slave systems are intact and the processing load is reduced, then fewer perseverative errors are likely to occur. This result further supports the suggestion that in this sample of mild to moderately head-injured patients the perseverative errors were due to an inability to sustain attention rather than cognitive inflexibility.

Successful performance on a card-sorting test relies on the ability to recognise a pattern of required responses (i.e., concept formation). The inability to do this is reflected by the failure to establish set score. However, in order to recognise a pattern of responding the relationship between the previously sorted cards and verbal feedback needs to be maintained, placing a heavy demand on working memory. The failure to establish set score, therefore, reflects both concept formation and working memory ability. As the visual dysfunction group scored significantly more failure to establish set scores than the executive dysfunction group this result suggests a hierarchy of cognitive processing. That is, conceptual ability can only be determined when working memory is intact. Greve et al. (2002) presented a similar proposal of hierarchical dependency involving the cognitive processes of set shifting, problem-solving, and response maintenance. They proposed that if a person is unable to shift set then problem-solving ability cannot be demonstrated. Similarly, if they are unable to problem-solve their ability to maintain set cannot be demonstrated. In light of the present findings, though, it could be argued that response maintenance, reflecting working memory, is a lower-order process than problem solving.

As mentioned previously the auditory dysfunction group was omitted from the main analyses due to its small sample size; so it was not possible to adequately test the phonological loop hypothesis. Nevertheless, a review of the baseline data completed by patients who did not meet the inclusion criteria was informative. Of those whose Digit Span F-B string was greater than two, 70% also scored below 28th percentile on the Visual Patterns Test, 10% scored below 25th percentile on only one test of executive function, and 20% scored above 25th percentile on all other tests. It seems that for the majority of head-injured patients with auditory working memory impairment, visual working memory was also impaired. Conversely, the majority of patients with impaired visual working memory performed within the normal range on the auditory working memory measure. Reports of a contribution of the right parietal cortex to verbal working memory tasks could explain the difficulty in finding patients with selective auditory working memory impairment. For example, tasks that alter the visual-spatial characteristics of to-be-remembered stimuli have been found to negatively affect backward but not forward recall (Li & Lewandowsky, 1995); poor performance on Backwards Digit Span with normal performance on Forwards Digit Span has been shown to be associated with impaired visual scanning in patients with left hemiplegia (Weinberg, Diller, Gerstman, & Schulman, 1972); and Ravizza, Behrmann, and Fiez (2005) found impaired performance on a verbal n-back task by a patient with a right parietal lobe lesion that could not be attributed to a more general involvement of the central executive. Overlapping areas of activation have also been found in both hemispheres for verbal working memory and spatial attention tasks (LaBar, Gitelman, Parrish, & Mesulam, 1999). In contrast, neither activation of Broca's area proposed to reflect the articulatory rehearsal loop, nor Wernicke's area proposed to reflect the phonological store (see Baddeley, 1998), have been found in neuroimaging studies investigating visuospatial working memory (Awh & Jonides, 2001; Smith et al., 1995, 1996), even though left hemisphere activation has been shown for visual working memory (McCarthy et al., 1996; Smith et al., 1995).

Despite being omitted from the main analyses separate analyses showed significantly poorer performance by the auditory dysfunction group than by the head-injured controls for the categories achieved and total errors indices. In comparison to the other dysfunction groups, this group's performance was equivalent to that of the executive dysfunction group on all dependent measures but was better than the visual dysfunction group on the random errors and failure to establish set indices. Although interpretation of these results needs to be treated cautiously, due to the small participant number, they provide some indication that the visuospatial sketchpad maybe a more critical component than the phonological loop in card sorting test performance.

The correlational analyses also provide support for the role of the visuospatial sketchpad. Even though the tests of executive functioning and information processing variably correlated with the categories achieved, total errors, random errors, and/or failure to establish set scores, none were significantly correlated with all measures in both feedback conditions. Visual

Patterns Test percentiles, on the other hand, were not only significantly correlated with all these measures in both feedback conditions but the sizes of the correlations were substantial. Partial correlations with the Visual Patterns Test percentiles controlled for, also showed a reduction in the strength of the correlations between the card sorting test variables and the executive tasks, which suggests that visual working memory plays a major role in determining card sorting test errors.

Until now the role of the visuospatial sketchpad in WCST performance has only been inferred from correlational studies involving participants with schizophrenia or schizotypic traits (see Chapter 5). In previous research the phonological loop and central executive have received the most attention. Although the extent of contribution by the phonological loop could not be sufficiently established the present findings consistently indicate significant involvement of the visuospatial sketchpad in addition to an impaired central executive. On all measures in which the dysfunction groups showed poorer performance than the head-injured controls the visual dysfunction group's performance was significantly worse than that of the executive dysfunction group.

In Baddeley's (2001) more recent version of the working memory model the central executive is described as a purely attentional system that combines information from long-term memory with existing environmental stimuli. In the WCST the environmental stimulus is visual (shapes and colours) and spatial (location and movement of the cards) with some auditory input (verbal feedback). As the central executive is not attributed with storage capacity it seems reasonable to assume that information related to this predominantly visuospatial task would be stored in the visual store and maintained by the spatial subcomponent, the inner scribe. Therefore, an impaired central executive would result in poor WCST performance but without the additional support of an intact visuospatial sketchpad, performance could be expected to be worse, as was found in the present experiment.

According to Baddeley (1996) if the central executive is unable to switch attention between two or more stimuli, perseveration occurs. However, if the central executive's function of being able to focus attention in the presence of irrelevant information is impaired, distractibility occurs. Perseverative and random errors both contribute to the categories achieved score but as Barceló (1999) has shown these errors are associated with different prefrontal neural networks, which he suggested, reflect these distinct cognitive processes. In an event-related potentials study with 32 college students, Barceló found that with the selection of visually relevant information, perseverative errors were related to a disruption in the frontal-extrastriate network, which evoked a P3b response. Distractions, however, were related to P2 activity in the frontal-central brain regions consistent with a loss of inhibitory control. Results from the current experiment in which no participant exhibited strong perseverative tendencies, suggests that the significantly poorer performances by the dysfunction groups was due to an inability to inhibit competing responses in working memory. This impaired process was represented primarily by the number of random errors made but also by the failure to establish set score.

One of the limitations of working with a closed head injured population, in which the patterns of impairment can be diverse, is attaining a sufficient number of participants who meet the inclusion criteria such that statistical analysis has adequate power. Power at .8 or above with a significance level of .05 is desirable. According to Kirk (1982) the numbers obtained in the present study equate to either .7 power at the .05 significance level or .8 power at the .10 significance level. Therefore, as the optimal power level was not achieved it is not possible to conclude that there is no effect of visual feedback on WCST performance. Nevertheless the obtained power level and the significantly poorer performance of the visual dysfunction group adequately support the critical role of visuospatial working memory in card sorting test performance.

The use of cut-off scores to determine impairment may also have been a limitation of the present study. Whilst this method is conventional in research screening (Lezak et al., 2004), in clinical practice an individual's estimated premorbid level of functioning (i.e., FSIQ) is also taken into account. For example, an individual whose FSIQ is estimated as being within the average range would not be classified as impaired at the 30th percentile as their performance would be within 1 *SD* below the mean. However, an individual with an estimated FSIQ within the superior range would be considered impaired at the 30th percentile as this would be more than 1 *SD* below their average level of functioning. Conversely, an individual with an estimated FSIQ below average could be judged as performing within their normal range at the 25th percentile. In this experiment premorbidly high functioning participants may have been excluded. However, lower functioning participants were still required to meet the inclusion criteria, which meant performing within the average range on some tests. Individualising a determination of impaired/unimpaired for screening purposes maybe established in future research but as yet is not widely implemented. Although there was a significant difference between the groups in this experiment for FSIQ, when analyses were performed with FSIQ as a covariate the group differences remained. Therefore, the basis of the findings is not due to differences in FSIQ.

From a clinical perspective the present findings have implications for clinical practice that will be discussed more fully in the next chapter. Generally, the WCST is used in practice to assess executive function, specifically hypothesis testing and concept formation (Kessler, 2006). If, as suggested, working memory is a lower order cognitive process then an accurate assessment of these functions may not be possible unless working memory is intact.

This is the first study to investigate the relationship between the different components of the working memory model and card sorting test performance in a group of closed head-injured patients. In the next and final chapter the results of this experiment and those of the previous experiments in this thesis will be discussed with respect to the original WCST procedure and scoring system and the implications for clinical assessment and future research.

CHAPTER 11

General Discussion

Originally, Grant and Berg (1948) developed the Wisconsin Card Sorting Test (WCST) to assess the relationship between cognitive flexibility and a pattern of positively reinforced responses. Combining many features of a variety of abstract reasoning tests it later became the 'gold standard' for assessing executive functioning (Royall et al., 2002). It is relatively sensitive to frontal lobe dysfunction and its lack of specificity, once a major concern and the focus of many research studies, has largely been explained by the discovery of the three frontal-subcortical circuits (see Chapter 2). Nonetheless, the WCST is an extremely complex task that requires the involvement of many cognitive processes including concept generation, cognitive flexibility, sustained attention, working memory, and response inhibition. In clinical practice poor performance is generally attributed to an inability to detect the appropriate pattern of responses (concept formation) or to perseverative tendencies. A better understanding of the cognitive processes underlying WCST performance and their relationship to the WCST index scores could potentially influence assessment decisions and rehabilitation needs (Greve et al., 2002).

The central aim of the present thesis was to clarify the role of one cognitive process, working memory, in WCST performance. Specifically, it aimed to determine the contribution to WCST performance of each individual component of the working memory model. In addition, the series of experiments aimed to examine the relationship between working memory and the WCST index scores and to ascertain whether the presence or absence of visual feedback would differentially affect card sorting test performance.

Well-developed theories offer a foundation for exploring and conceptualising various cognitive processes, such as attention, memory, and executive functions (Sohlberg & Mateer, 2001). Experimental results that support a theoretical model help guide clinicians in their assessment and treatment activities. The findings from the series of experiments presented in this thesis have not corresponded with nor advanced the knowledge of the majority of theories presented in Chapter 2. However, Baddeley's (1986, 1998, 2001) and Logie's (1995, 2003) models of working memory, which have provided an explanation for and an understanding of a range of behavioural phenomena (e.g., language acquisition, environmental dependency, mental synthesis) also provide an explanation for the present findings.

11.1 Overview of the findings

Experiments 1A and 1B assessed performance of a group of university students on a range of working memory tasks and on two computerised versions of the WCST: the original (Heaton, 1981; Heaton et al., 1993) and the Madrid Card Sorting Test (MCST: Barceló & Knight, 2002). The results indicated that significantly more total errors were made on the MCST than on the WCST; participants with lower working memory ability in all modalities performed more poorly on the MCST whereas only participants with reduced spatial working memory performed poorly on the WCST; and significantly more nonperseverative than perseverative errors were made on the MCST whereas the reverse occurred on the WCST. As a number of procedural differences were noted between the two card-sorting tests (e.g., presence or absence of visual feedback from previous response cards; error definitions) the data were reanalysed after ambiguous cards were omitted from the WCST and errors were redefined according to Barceló and Knight's criteria (see p.116). The reanalyses continued to show that low scorers on all working memory tasks made a significantly higher percentage of total errors on the MCST than on the WCST. In contrast to the original analysis, more nonperseverative than perseverative errors were indicated on the rescored WCST. The findings from these two experiments supported the hypothesis of working memory involvement in card sorting test performance, indicating a link between working memory ability and nonperseverative errors, and identifying the need for further investigation into the effect of visual feedback on performance.

After determining appropriate secondary tasks (Experiment 2) the contribution made by the individual components of working memory to card sorting test performance was investigated using a dual-task paradigm in Experiment 3. The effect of visual feedback was also examined as this appeared to be the most salient difference between the WCST and MCST in the previous experiments. The results indicated that whilst all working memory components contribute to successful card sorting test performance the involvement of the phonological loop and visual store are differentially affected by the presence or absence of visual feedback. These results generated the hypotheses that the phonological loop, whilst involved in both feedback conditions, provides a greater contribution in the presence of visual feedback whereas the visual store is only involved when visual feedback is absent.

The final experiment investigated these hypotheses by assessing card sorting test performance with and without visual feedback in a group of closed head-injured patients differentially impaired on a range of executive and working memory tasks. The relationship between working memory ability and card sorting test index scores was also examined. Although the results showed no consistent effect of feedback, the performance of patients with combined executive and visual working memory impairment was significantly poorer than any other group on a number of card sorting test measures. These results provided further evidence for the role of working memory, particularly the visuospatial sketchpad, in card sorting test performance. Patients in the visual dysfunction group made significantly more random errors and failure to establish set scores. These findings were interpreted as reflecting an inability to inhibit competing responses that impacted on problem-solving and conceptual abilities. The results also suggested that some perseverative errors reflect distractibility rather than perseveration.

11.2 WCST-working memory link

The two multiple component models of working memory, on which this thesis is based, were developed by Baddeley and Hitch (Baddeley, 1986, 2001; Baddeley & Hitch, 1974) and Logie (1995, 2003). Whilst there are conceptual differences between them the fundamental components are essentially the same, comprising a central executive, two subcomponents for the storage (phonological store) and rehearsal (articulatory rehearsal loop/inner speech) of auditory-based information, and two subcomponents assumed to be capable of holding (visual store) and manipulating (inner scribe) visuospatial information (see Chapter 4).

Working memory has been considered one of many possible cognitive processes underlying performance on card sorting tests developed to assess executive functioning. Other processes proposed include concept formation, cognitive flexibility, sustained attention, and response inhibition. However, some of these processes have been shown to be functions of the central executive (Baddeley, 1996, 2001; Miyake et al., 2000; 2001). Therefore, based on the findings of the preceding experiments it could be argued that working memory is the cognitive process upon which other processes are contingent. As reviewed in the previous section, nonclinical participants with reduced working memory ability performed more poorly on two versions of the WCST; performance was adversely affected by all concurrent secondary tasks designed to interfere with the specific working memory components; and closed head-injured patients with impaired central executive, auditory, or visual working memory performed significantly worse than the head-injured controls.

Numerous studies have successfully used the dual-task paradigm to separate the involvement of the respective components of working memory on a range of verbal and visual tasks (see Chapters 4, 5, 9). For successful performance of the tasks upon which the inclusion criteria were based in the final experiment, intact working memory ability is required. The Trail Making Test requires task switching, the FAS requires the on-line maintenance of instructions and monitoring of responses similar to random letter generation, and the Brixton requires the monitoring of previous responses and the integration of information from long-term memory and environmental stimuli - functions attributed to the central executive (see Chapters 4, 10). Digit Span requires the storage and manipulation of aurally presented material - functions of the phonological loop (Baddeley, 2001). And the Visual Patterns Test requires the storage of a visually presented static pattern - a function of the visual store (Della Sala et al., 1999; Logie, 1995).

Following their factor analytic study of the WCST, Greve et al. (2002) proposed that the factors and clusters obtained reflected a hierarchy of cognitive processing with three relatively independent processes (set shifting/cognitive flexibility, problem-solving/hypothesis testing, response maintenance). They suggested that impairment in one process could not be demonstrated unless the lower-order processes were intact. In a follow-up large-scale confirmatory factor analytic study Greve et al. (2005) found support for this three-factor solution, however only a one-factor solution reflecting general executive functioning was statistically sound (see Chapter 3, p.33). In light of the present findings it is proposed that this one factor may be heavily dependent on working memory.

Cognitive inflexibility (associated with perseveration) can be explained by the failure of the attentionally limited central executive to override an action that is being maintained by environmental stimuli (Baddeley, 1996, 2001, 2002; Baddeley, Chincotta et al., 2001). With respect to the WCST this stimuli refers to the consecutive positive reinforcement of responses prior to a change in criterion and so requires task switching. Hypothesis testing and concept formation also rely on intact central executive functioning in that they require the maintenance and monitoring of previous card sorts and the integration of this information with verbal feedback and prior knowledge from long-term memory (dual-tasking). Response maintenance relies on the ability to selectively attend to relevant information while inhibiting irrelevant information in the presence of competing responses (focussed selective attention).

Baddeley and colleagues (Baddeley, Chincotta et al., 2001) have provided evidence for a link between the central executive and phonological loop in task switching. As reviewed in Chapter 4 verbal trails (a secondary central executive task) significantly interfered with performance on a primary arithmetic task in both baseline and switching conditions irrespective of external cues. Articulatory suppression, however, only interfered with performance in the switching condition and only when the external cues were omitted. These results indicated a role for the central executive in the process of switching per se and suggested that maintenance of the switching program was dependent on the phonological loop. In Experiment 3 both verbal trails and articulatory suppression interfered with card sorting test performance. In Experiment 4 all participants in the dysfunctional groups, except two, scored below the 25th percentile on the task switching Trail Making Test. Taken together these findings contribute additional evidence that working memory is the underlying process governing WCST performance. Given the results in Experiment 3, in which articulatory suppression had a greater effect in the presence of visual feedback, the question still remains as to whether the role of the phonological loop is also to assist in inhibiting competing responses. If this is not an additional role then, considering Baddeley et al.'s findings, a greater reduction in performance should have occurred in the no visual feedback condition, when external cues (previous response cards) were absent.

Whilst both slave systems appear to be involved in card sorting test performance the results from the last two experiments indicate a more prominent role for the visuospatial sketchpad. In Experiment 3 the results showed no effect of the secondary visual interference task on performance in the visual feedback condition whereas there was a significantly adverse effect when visual feedback was absent. This result suggested that storage of visual information was only required when previous response cards were not visible. As this hypothesis was not supported in Experiment 4 it could be argued that the phonological loop is relied upon to maintain information about previous responses as has been demonstrated in studies of visually presented digits (Baddeley, 2001; Vallar & Papagno, 2002). However, the retention of visually presented material, whether presented as a single complex pattern (e.g., Visual Patterns Test: Della Sala et al., 1999) or as a sequence of items (e.g., letters, words), has also been found to be less affected by articulatory suppression than verbally presented material (see Chapter 5). These findings suggest that when the task is predominantly visual, as is the case with card sorting, then recruitment of the visual store is necessary. As discussed in Chapter 10 the lack of a feedback effect in Experiment 4 may have been due to impaired spatial working memory being undetected in the visual dysfunction group. As was shown in Experiment 3 the secondary spatial working memory task affected performance in both feedback conditions.

The results from all experiments provide considerable support for the visuospatial sketchpad as a fundamental component in card sorting test performance, irrespective of the fact that Experiment 4 was unable to clarify the role of the visual store. Just as a connection between the central executive and phonological loop has been found in task switching, a similar link has been shown for the central executive function of selective attention and spatial working memory. Logie (1995) described the spatial component of working memory (the inner scribe) as a rehearsal system for the retention of movement sequences and of information in the visual store. In a review of working memory studies, Logie (2003) summarised "that at least one distinctive feature of the inner scribe system is that it may draw heavily on aspects of attentional control" (p.64). Fisk and Sharp (2003) found a disruption in performance of a visuospatial running memory task with concurrent random letter generation indicating central executive involvement of the visuospatial task. Smyth (1996) found that performance on a spatial working memory task was affected by shifts in attention and not eye movements. And Awh and Jonides (2001) have provided behavioural and neuroimaging evidence showing that attention directed to specific locations enhances visual processing and is a key component of spatial working memory. These overlapping processes of attention and spatial working memory could explain the similarity of the results in Experiment 3 between the effects of the secondary central executive task and secondary spatial working memory task on card sorting measures, irrespective of feedback condition.

In summary, the findings from this series of experiments suggest that working memory is an underlying cognitive process in card sorting test performance. This conclusion is supported by evidence from neuroimaging studies (reviewed in Chapters 2 and 5) that show an overlap in activation, involving the dorsolateral prefrontal circuit, for performance on the WCST and on all working memory tasks.

The tripartite model of working memory is supported by the present results as both visual and verbal codes have been shown to be involved in card sorting test performance. Furthermore, performance was not consistent across groups of closed head-injured patients who were differentially impaired on a range of executive and working memory tasks. The dual task manipulations in Experiment 3 also showed differences in performance that were dependent on the secondary task used. Baddeley (2000) has added an additional component to his model, the episodic buffer, which is assumed to be a temporary storage system that provides a temporary interface between the slave systems and long-term memory. Although successful performance on card sorting tests would seem to require the integration and storage of verbal (test instructions, verbal feedback) and visual (card design & placement) information, the design of the thesis experiments did not address Baddeley's concept of an episodic buffer and the results provide no insight into its feasibility.

Logie's (1995, 2003) model, on the other hand, appears to account quite well for the overall results. In contrast to Baddeley's model, Logie posits that perceptual information is firstly interpreted based on prior knowledge before gaining access to the working memory system. Although the card-sorting test itself is novel all perceptual aspects of it are easily interpretable from past experiences. Consistent with this model, the base knowledge about colours, geometrical shapes, numbers, cards, and conceptual relationships would then have direct access to the storage components of the respective slave systems. Information regarding the sorting rules, verbal feedback, and prior responses would be maintained in the phonological store by the rehearsal processes of the inner speech (articulatory rehearsal system). Information about the shapes, colours, and numbers of the visual array (i.e., the response cards) would be stored in the visual cache (visual store) and maintained by the inner scribe. As the inner scribe is also assumed to be a rehearsal mechanism for the retention of movement sequences it would be the mechanism for keeping track of card location. Finally the integration and monitoring of information within the executive functions (central executive) component of the model, from the slave systems and from the knowledge base, would be the mechanism that provides a mental workspace for hypothesis generation, inhibition, mental manipulation, and mental search.

The individual functions comprising the executive functions component of Logie's model were not investigated in this thesis. However, the results from Experiments 3 and 4 indicate that inasmuch as this component is of primary importance in successful card sorting test performance, when the visual cache and inner scribe are disrupted or impaired a further deficit in performance occurs.

Whilst the working memory model appears to account for variations in performance on card sorting tests there may be alternative explanations. Information processing speed has been proposed as mediating working memory capacity (Fristoe et al., 1997; Hartman et al., 2003). In Experiment 4 the executive dysfunction and visual dysfunction groups had significantly lower information processing scores than the head-injured controls. The correlational analysis also showed a significant moderate correlation between information processing percentiles and the card sorting test variables of categories achieved, total errors, random errors, and failure to establish set scores (see Table 10.5). However, these significant correlations were for the visual feedback condition only. If processing speed mediated working memory capacity per se one would expect the correlation between the variables to be consistent across all conditions. It may be that in the visual feedback condition more information requires monitoring and manipulation, that is, sorting rules, feedback, prior responses and the inhibition of the irrelevant visual stimuli. So, like juggling balls the more one has to deal with, the faster one needs to be in order to manipulate the items successfully.

Inhibition has been discussed as one of the many functions of the central executive. However, some researchers have proposed that working memory capacity may be dependent on the ability to resist interference from previously learned information or extraneous environmental information ((Lustig, Hasher, & Tonev, 2001). In a review article Lustig et al. report the results of research into the effect of no longer relevant information on working memory span. In many working memory tasks proactive interference increases with each span level, such as in the Digit Span, Visual Patterns Test, and Corsi Blocks. In one study in which the longest span of a reading span task was administered first rather than last, the span scores of older adults was higher than in the standard administration. In contrast with the usual age-related decline in working memory span, the older adults performed as well as the younger adults with the reversed administration. As working memory tasks are commonly used to predict performance on more complex tasks, Hasher and colleagues (Hasher, Zacks, & May, 1999, cited in Lustig et al., 2001) suggested that "if *irrelevant* information is not deleted from working memory, it may impair [the] integration of the *relevant* past and current information, leading to reduced speed and increased errors." (Lustig et al., 2001, p.112). In another study reviewed, the similarity of environmental distractors to target information was found to adversely affect the performance of both young and older adults if they were tested at non-optimal times of the day. Card sorting tests, particularly in the visual feedback condition, are laden with similar environmental distractors. If inhibitory control is an external function that influences working memory capacity rather than as a function of the central executive, then poorer performance in the visual feedback condition could have been expected. Nevertheless, the findings of the studies reviewed in Lustig et al. are persuasive and require further consideration with regards to the impact on the execution of complex tasks.

11.3 Clinical implications

In clinical practice performance on the WCST is primarily interpreted with respect to the processes of cognitive flexibility and problem-solving ability, functions that are dependent on the integrity of the central executive component of working memory. However, the present findings suggest that poor performance could also be attributed to deficits in either of the slave systems but in particular that of the visuospatial sketchpad. In Logie's (2003) model intact perceptual processes are required for interpretation and the activation of representations in long-term memory prior to the information being incorporated into the working memory system. Therefore, in clinical practice a patient's poor performance should alert the clinician to consider not only impaired executive functioning but also to further investigate the patient's visuoperceptual and visuospatial abilities. Correctly identifying the reason for poor WCST performance would allow for the development of appropriate rehabilitation programmes. For example, a programme designed to target problem-solving difficulties may have little effect if the underlying reason for poor WCST performance was an inability to adequately perceive and interpret the visual material. A redesign of the WCST could also allow the clinician to differentiate between poor performance due to perseveration and that due to distractibility/attentional deficits as has been demonstrated in the present series of experiments.

In the standardised version of the WCST (Heaton et al., 1993) ambiguous cards are used, the sorting criteria are undisclosed, there are two discontinuation rules (six categories or 128 cards), and perseverative errors are scored in relation to the immediately preceding category. Modifications to these procedural points have shown a reduction in patients' distress during administration (Nelson, 1976) and no reduction in sensitivity to impairment with the disclosure of the sorting criteria (Barceló & Knight, 2002; Nelson, 1976; Stuss et al., 2002). Greve et al. (2005) have argued that a more stable reflection of cognitive abilities can be achieved with a uniform discontinuation rule in which all cards are used and have suggested that information can be lost if the number of cards are too few.

Stuss et al. reported that the perseverative error definition that represents the immediate repetition of a response appears to be "a true pathognomonic sign of frontal… lobe disturbance" (p.399). However this definition, which was used in the present series of experiments, does not provide as substantial a measure of the ability to shift from a pattern of reinforced responses, as does the original perseverative error definition. Therefore, changes to the present WCST procedure seem warranted based on the aforementioned suggestions and the present findings.

With a clinical as well as a research application in mind, a redesign of the WCST is proposed incorporating the following procedures:

- The use of unambiguous cards only (i.e. 24)
- Discontinuation rule of 72 cards (i.e. 3 sets of 24)
- Disclosure of the sorting criteria and an explanation that the rule will change without warning, given prior to commencement of the test
- The first category determined by the patient/participant
- Six correct consecutive responses = a category
- Two perseverative error definitions (Stuss et al., 2000)
    - PPC = an incorrect response to a new category, which would have been a correct response for the immediately preceding category
    - PPR = an incorrect response that is the same as the immediately preceding incorrect response
- Random error (Barceló & Knight, 2002) = an incorrect response that is different from the immediately preceding response
- The first response following a completed category is <u>not</u> counted as an error
- The second response following a completed category is <u>not</u> counted as an error unless it is a perseverative error

The index scores would comprise the number of categories achieved, total number of errors, number of PPC errors, number of PPR errors, and number of random errors. As a measure of distractibility would be accounted for in the PPR score, a loss of set/failure to maintain set score would be unnecessary.

11.4 Future research

The findings reported in this thesis have added to the growing body of research identifying working memory as one critical underlying process in WCST performance. The primary contribution of this research has been the identification of the role of the visuospatial sketchpad, which has been demonstrated by experimental design in the earlier experiments and confirmed, in the final experiment involving patients with a closed head injury. The findings have also provided support for the differentiation between perseveration and distractibility associated with WCST errors.

In many research studies examining WCST processes, the provision of visual feedback has been overlooked in the design of the versions used. The results of Experiment 3 suggest that the contribution to performance made by both the phonological loop and the visual store might vary depending on whether previous response cards remain visible or are hidden from one trial to the next. The present results also suggest that the increased memory and processing loads on the central executive in the absence of visual feedback significantly affect performance on card sorting tests. As the central executive is now generally accepted as being non-unitary, determining which functions are more heavily recruited in the presence or absence of visual feedback could have important implications. For example, does performance with no visual feedback rely on updating more than on inhibitory control? Is inhibitory control critical to successful performance when visual feedback is present; and to what extent does the phonological loop contribute to inhibitory control? Is inhibitory control a function of the central executive at all or is it an independent function, as suggested by Lustig and colleagues (Lustig et al., 2001), that mediates working memory capacity? If brain impairment was found to differentially impair functions of the central executive, as well as the slave systems, then card sorting test results could be misleading if the presence or absence of visual feedback is not taken into account. The effect of visual feedback is, therefore, a variable that requires further investigation.

In the design and validation of the Visual Patterns Test (VPT) Della Sala et al. (1999) provided the results from experiments with healthy participants and brain-damaged patients showing a double dissociation between the Visual Patterns Test and the Corsi Blocks. This represented a fractionation of the visuospatial sketchpad into a visual and a spatial component, respectively. Whilst the evidence that the Visual Patterns Test is more heavily loaded on visual working memory is quite strong, the questions raised by the results of Experiments 3 and 4 indicate that further investigations into its structure or the pursuit of a purer measure of visual working memory is still required. As the studies reviewed in Lustig et al. (2001) suggest that the design of working memory span tasks may not reliably reflect working memory capacity due to proactive interference, the development of alternative designs also requires consideration.

Neuropsychological assessments are, by their very nature, time consuming as even a basic battery of tests needs to cover the major domains of cognition (e.g., intelligence, language, visuospatial processing, memory and learning, attention/concentration, executive functioning). Therefore, if a test can provide valid and reliable information about more than one cognitive function (e.g., perseveration vs distractibility), then it can guide the clinician's choice in the use of more specific tests. The proposed redesign of the WCST presented in this thesis maybe such a test. However, it requires piloting in a normally functioning population and validation across a wide range of clinical populations.

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APPENDIX A

Personality Questionnaire

Thank you for agreeing to complete the following questionnaire. It is much appreciated

The aim of this study, which is part of a PhD project, is to determine the validity of a personality scale. It is, therefore, very important that *all* questions are completed.

It will take approximately 5-10 min to complete the questionnaire

Please indicate by circling: male female

Instructions: Please answer the questions by putting a circle around the "YES" or the "NO" following each question. There are no right or wrong answers, and no trick questions. Work quickly and do not think too long about the exact meaning of the questions.

PLEASE REMEMBER TO ANSWER EACH QUESTION

1. Do you like plenty of excitement and bustle around you?................................ YES NO
2. People sometimes find me aloof and distant... YES NO
3. Have you often got a restless feeling that you want something but do not know what?.. YES NO
4. Have you ever had the sense that some person or force is around you even though you cannot see anyone?.. YES NO
5. Do you nearly always have a "ready answer" when people talk to you?............... YES NO
6. People sometimes comment on my unusual mannerisms and habits..................... YES NO
7. Do you sometimes feel happy, sometimes sad, without any real reason?.............. YES NO
8. Are you sometimes sure that other people can tell what you are thinking?............. YES NO
9. Do you usually stay in the background at parties and "get-togethers"?................ YES NO
10. Have you ever noticed a common event or object that seemed to be a special sign for you?... YES NO
11. As a child, did you always do as you were told immediately and without grumbling? YES NO
12. Some people think I am a bizarre person... YES NO
13. Do you sometimes sulk?... YES NO
14. I feel I have to be on my guard even with friends...................................... YES NO
15. When you are drawn into a quarrel, do you prefer to "have it out" to being silent, hoping things will blow over... YES NO
16. Some people find me a bit vague and elusive during a conversation................... YES NO
17. Are you moody?.. YES NO

18. Do you often pick up hidden threats or put-downs from what people say or do?...... YES NO
19. Do you like mixing with people?...... YES NO
20. When shopping do you get the feeling that other people are taking notice of you?... YES NO
21. Have you often lost sleep over your worries?...... YES NO
22. I feel very uncomfortable in social situations involving unfamiliar people...... YES NO
23. Do you sometimes get cross?...... YES NO
24. Have you had experiences with astrology, seeing the future, UFOs, ESP or a sixth sense?...... YES NO
25. Would you call yourself happy-go-lucky?...... YES NO
26. I sometimes use words in unusual ways...... YES NO
27. Do you often make up your mind too late?...... YES NO
28. Have you found that it is best not to let other people know too much about you?... YES NO
29. Do you like working alone?...... YES NO
30. I tend to keep in the background on social occasions...... YES NO
31. Have you often felt listless and tired for no good reason?...... YES NO
32. Do you ever suddenly feel distracted by distant sounds that you are not normally aware of?...... YES NO
33. Are you rather lively?...... YES NO
34. Do you often have to keep an eye out to stop people taking advantage of you?..... YES NO
35. Do you sometimes laugh at a dirty joke?...... YES NO
36. Do you feel that you are unable to get "close" to people?...... YES NO
37. Do you often feel "fed-up"?...... YES NO
38. I am an odd, unusual person...... YES NO
39. Do you feel uncomfortable in anything but everyday clothes?...... YES NO
40. I find it hard to communicate clearly what I want to say to people...... YES NO
41. Does your mind often wander when you are trying to attend closely to something?... YES NO
42. I feel very uneasy talking to people I do not know well...... YES NO
43. Are you completely free from prejudices of any kind?...... YES NO
44. I tend to keep my feelings to myself...... YES NO
45. Do you often get "butterflies in your tummy" before an important occasion?....... YES NO

Please check to see that you have answered all the questions for this section, thank you.

Information Sheet for Participation in Research Project

University of Tasmania

"Working Memory and Wisconsin Card Sorting Test Performance."

Chief Investigator: Dr Clive Skilbeck
Student Researcher: Jan Martin

You are invited to take part in a PhD project in psychology. The chief investigator is Dr Clive Skilbeck, and the PhD researcher is Jan Martin. The aim of the project is to examine the relationship between working memory and performance on the Wisconsin Card Sorting Test. A better understanding of these tests will potentially benefit neuropsychological patients in the future. Exclusion criteria include individuals over 45 years, the presence of anxiety or depression, any neurological or psychological condition, uncorrected hearing or vision problems, colour-blindness, drug or alcohol dependency, and the taking of any medication which is likely to affect cognitive ability.

The study has **two sessions** with one week between each session.

Each session will be for approximately **one hour** and will consist of visual and verbal tasks involving patterns and numbers and some simple computer tasks.

In the event of fatigue a break will be permissible between tasks.

All study results will remain confidential. You will not be personally identifiable as you will be allocated an identification number which will be used on all assessment forms and data analyses.
Assessment data will be kept in locked storage or on secure computer network in the School of Psychology and will be kept separately from personal information to ensure anonymity. Personal information will be destroyed after data collection and analyses. Overall results will be made available on the web at the completion of the study.

You may withdraw from the study at any point without prejudice to your academic standing.

If you wish to be part of this study, have questions, or require further information please contact Jan Martin on 6225 0233 or Dr Clive Skilbeck on 6226 7459.

The project has been approved by the Southern Tasmania Social Sciences Human Research Ethics Committee. If you have any ethical concerns or complaints about the project, you may contact the Chair of the Southern Tasmania Social Sciences Human Research Ethics Committee, A/Professor Margaret Otlowski, on (03) 6226 7569, the Executive Officer, Amanda McAully on (03) 6226 2763 or you may choose to discuss these concerns confidentially with a University Student Counsellor.

Thank you for your time.

Consent to Participate in a Research Project

University in Tasmania

"Working Memory and Wisconsin Card Sorting Test Performance."

I have read and understood the information sheet for this study and acknowledge that I do not meet any of the exclusion criteria presented in the medical questionnaire.

I understand that the study involves the following procedures:

- There will be two sessions, one week apart.
- Each session will last about one hour.
- Each session will consist of visual and verbal tasks involving patterns and numbers, and some simple computer tasks.
- I may take a break between tasks if I become fatigued.

I understand that all research data will be treated as confidential and I will not be personally identifiable.

Any questions that I have asked have been answered to my satisfaction.

I agree that research data gathered for the study may be published provided that I cannot be identified as a participant.

I would like to receive a copy of the results obtained from this study. Yes/No

I agree to take part in this project and understand that I may withdraw at any time without prejudice.

Name of participant: ____

Signature of participant: ____________________ Date____________

Statement by Investigator

I have explained this study and the implications of participation in it to this volunteer and I believe that he/she understands it, and that this consent is based on adequate information.

Name of investigator:____

Signature of investigator: ____________________ Date____________

Medical History Questionnaire

Contact information

Date:....../....../.......   ID No:..............................

Name:...

Address:... Postcode:......

Date of Birth: ...... /...... /.........   Age:............ years ....months

Phone: Home...................... Other.........................

Medical History

Are you currently suffering from anxiety or depression?...........................

Do you have a heart condition or any other serious physical condition?.........

Are you currently taking any prescription medication? If so, what medication?...

Have you in the past taken any medications for psychological condition(s)? If so, what medications?..

Do you have any difficulties with hearing or vision?...

Are you colour-blind?..

Have you ever had treatment for drug or alcohol problems?..................

Have you ever had or are you subject to any of the following:

Fits or Convulsions................	*Yes*	*No* ....
Epilepsy..............................	*Yes*	*No* ....
Giddiness.............................	*Yes*	*No* ....
Concussion...........................	*Yes*	*No* ....
Severe Head injury.................	*Yes*	*No* ....
Loss of Consciousness...........	Yes	*No* ...

Note: It is a formal requirement of the Southern Tasmanian Social Sciences Human Research Ethics Committee of the University of Tasmania that the information provided on this questionnaire be held under security to comply with confidentiality regulations and to protect your privacy. You can be assured that information will be available only to the principal researcher and not to any other party. The questionnaire will be destroyed following the completion of the project.

Key to the Raw Data – Experiment 1A

wcat	WCST categories achieved score
wpe	WCST perseverative errors
wnpe	WCST nonperseverative errors
wfms	WCST failure to maintain set score
wtep	WCST percentage total errors
mtep	MCST percentage total errors
mee	MCST efficient errors
mre	MCST random errors
mnpe	MCST nonperseverative errors
mpe	MCST perseverative errors
dsb-string	Digit Span Backwards String
lns	Letter Number Span
vpt	Visual Patterns Test
cdl	Coughlan Design Learning
sdrt	Spatial Delayed Response Task
ssf	Spatial Span Forwards
ssb	Spatial Span Backwards
sst	Spatial Span Total

EXPERIMENT 1A Raw Data Set

	Schizotypy				WCST					MCST					Auditory w-m		Visual w-m		Spatial w-m			
ID#	score	25%	sex	FSIQ	wcat	wpe	wnpe	wfms	wtep	mtep	mee	mre	mnpe	mpe	dsb-string	lns	vpt	cdl	sdrt	ssf	ssb	sst
33	18	High	female	113	6	4	3	0	1.4	4.4	4	1	5	0	5	12	15	8.5	32	10	12	22
52	13	High	female	98	6	4	3	0	1.4	5.1	6	0	6	0	7	11	10	7	31	10	10	20
59	18	High	female	107	6	6	6	0	7.8	16.8	6	6	12	5	4	12	13	9	30	12	10	22
93	20	High	female	111	6	6	5	1	6.2	10.9	6	2	8	1	6	11	10	6.5	26	12	10	22
168	12	High	female	116	6	7	7	1	8.8	10.9	7	3	10	2	5	12	10	5	32	10	9	19
170	20	High	female	117	6	5	5	2	4.6	9.5	7	1	8	3	7	12	13	9	30	11	11	22
173	12	High	female	111	6	5	4	0	3.9	8.7	4	7	11	1	6	16	13	6.5	32	13	11	24
178	12	High	female	107	6	4	2	0	8.6	8	7	2	9	2	4	15	13	6.5	32	10	10	20
198	16	High	female	103	6	6	3	0	4.2	12.4	9	4	13	0	4	12	11	8.5	31	9	8	17
199	12	High	female	112	6	10	7	0	12.8	47.4	3	16	19	22	3	9	7	5.5	30	10	9	19
260	13	High	female	122	6	4	3	0	1.4	12.4	8	3	11	2	4	14	6	5	29	5	9	14
263	12	High	female	113	6	7	8	0	10.8	4.4	5	1	6	0	4	12	12	6.5	29	8	8	16
270	15	High	female	110	6	7	7	1	9.1	15.3	11	3	14	1	6	12	11	7	31	12	10	22
283	18	High	female	94	6	4	3	0	1.4	4.4	6	0	6	0	3	12	8	4	31	6	9	15
304	13	High	female	101	6	10	2	1	8.2	5.8	4	0	4	2	4	11	13	8.5	31	9	10	19
307	13	High	female	105	6	7	3	0	5.2	22.6	11	6	17	4	5	12	10	5.5	32	8	9	17
415	13	High	female	112	6	8	5	0	9.2	13.1	8	4	12	4	4	10	11	3	30	8	9	17
416	17	High	female	115	6	5	4	0	4.1	11.7	11	4	15	1	5	14	11	7.5	31	10	11	21
421	17	High	female	102	6	6	7	0	9.1	12.4	4	8	12	1	5	8	8	4.5	27	8	7	15
432	17	High	female	100	6	7	5	0	7.9	11.7	6	8	14	0	4	13	13	8	30	8	9	17
441	16	High	female	107	6	4	3	0	1.4	17.5	11	7	18	1	3	8	8	3	30	7	7	14
456	16	High	female	106	6	10	9	0	15.7	6.6	7	0	7	1	5	9	8	4	32	10	9	19
474	14	High	female	105	6	7	5	0	7.7	8.7	6	3	9	0	3	6	12	4	31	11	9	20
479	21	High	female	113	6	8	6	2	8.2	32.8	9	11	20	8	3	9	11	6	31	6	7	13
490	15	High	female	100	6	10	5	1	10.2	10.2	7	0	7	5	5	10	7	3.5	30	10	8	18
498	18	High	female	110	6	3	2	0	7.4	6.6	4	2	6	0	7	15	11	7.5	32	10	10	20
517	14	High	female	82	6	6	6	1	7.2	17.5	5	5	10	5	2	8	9	3.5	32	9	8	17

EXPERIMENT 1A Raw Data Set

	Schizotypy				WCST					MCST					Auditory w-m		Visual w-m		Spatial w-m			
ID#	score	25%	sex	FSIQ	wcat	wpe	wnpe	wfms	wtep	mtep	mee	mre	mnpe	mpe	dsb-string	lns	vpt	cdl	sdrt	ssf	ssb	sst
518	14	High	female	115	6	7	7	1	9.3	8.7	7	4	11	0	4	15	10	8	32	10	10	20
539	18	High	female	107	6	7	3	3	5.1	16.8	12	5	17	3	4	12	11	5.5	32	11	8	19
541	15	High	female	106	6	6	21	0	21.4	10.2	6	3	9	2	5	11	9	6.5	32	11	9	20
546	16	High	female	106	6	8	5	2	7.4	11.7	4	3	7	4	4	12	8	5.5	25	9	10	19
572	15	High	female	100	6	9	11	1	14.3	13.1	5	4	9	2	4	11	13	7.5	32	6	9	15
29	15	High	male	103	6	6	6	1	7.1	10.9	8	6	14	1	6	11	9	6	27	9	9	18
106	15	High	male	106	6	4	5	1	3.8	10.2	9	1	10	0	4	12	11	7.5	31	10	10	20
121	14	High	male	110	6	8	8	0	13.6	10.9	10	1	11	1	3	11	11	5.5	26	10	9	19
138	13	High	male	110	6	11	9	2	14	22.6	8	8	16	5	3	11	11	4	31	9	6	15
273	16	High	male	112	6	9	5	1	8.9	5.8	7	0	7	0	2	10	9	5	31	9	6	15
480	13	High	male	107	6	9	21	3	19.3	18.9	7	9	16	6	6	13	12	7	30	10	9	19
491	15	High	male	106	6	6	4	0	5.5	14.6	10	3	13	3	6	16	10	5	32	10	10	20
496	20	High	male	111	6	8	4	1	7	8	6	2	8	1	3	13	10	8	30	9	6	15
510	20	High	male	100	6	6	4	1	4.6	12.4	7	3	10	3	4	10	11	6	28	8	10	18
550	16	High	male	105	6	17	10	0	23.1	35.8	4	15	19	14	3	7	8	6.5	22	8	6	14
556	15	High	male	102	6	5	3	0	2.8	9.5	10	0	0	0	3	11	13	8	29	10	9	19
559	15	High	male	118	6	4	3	0	1.4	12.4	9	2	11	2	3	14	13	6	27	10	9	19
576	17	High	male	103	6	4	4	0	2.8	11.7	10	1	11	1	3	12	11	4.5	31	9	9	18
21	1	Low	female	108	6	4	3	0	1.4	5.1	7	0	7	0	3	7	11	7.5	31	8	10	18
38	5	Low	female	107	6	6	5	1	5.6	9.5	10	1	11	1	3	10	15	8.5	32	13	9	22
47	3	Low	female	96	6	7	8	0	11.5	10.9	6	1	7	2	4	11	11	6	31	6	10	16
50	2	Low	female	107	6	7	4	1	6.2	5.1	2	3	5	2	6	12	10	5.5	30	11	8	19
62	5	Low	female	102	6	4	4	0	2.7	14.6	6	6	12	2	3	11	12	8.5	32	10	8	18
95	0	Low	female	105	6	6	1	0	2.8	6.6	5	1	6	1	4	10	12	6	32	10	11	21
130	3	Low	female	107	6	4	4	0	2.8	10.9	9	3	12	2	4	13	10	6.5	32	10	10	20
159	3	Low	female	110	6	8	8	0	11.9	15.3	5	5	10	4	3	11	8	4.5	31	10	10	20
169	4	Low	female	107	6	6	1	1	1.4	13.1	2	6	8	4	4	11	10	4.5	31	9	8	17

EXPERIMENT 1A Raw Data Set

	Schizotypy				WCST					MCST					Auditory w-m		Visual w-m		Spatial w-m			
ID#	score	25%	sex	FSIQ	wcat	wpe	wnpe	wfms	wtep	mtep	mee	mre	mnpe	mpe	dsb-string	lns	vpt	cdl	sdrt	ssf	ssb	sst
194	3	Low	female	102	6	5	3	1	2.6	20.4	8	10	18	3	4	8	11	8.5	30	11	8	19
220	4	Low	female	103	6	7	4	0	7.9	5.1	6	0	6	1	5	10	12	4	32	12	11	23
222	1	Low	female	108	6	11	8	1	15.2	5.8	5	0	5	2	5	13	13	8	29	12	7	19
226	4	Low	female	105	6	4	2	0	8.6	11.7	4	0	4	6	5	12	10	5	31	10	10	20
236	0	Low	female	105	6	13	14	0	21	20.4	12	5	17	4	2	11	10	7.5	26	9	8	17
241	4	Low	female	115	6	6	7	0	9.1	21.1	8	7	15	6	4	11	7	6	31	12	10	22
250	5	Low	female	111	6	6	7	0	8.9	8.7	10	1	11	0	3	10	10	4	32	7	10	17
252	1	Low	female	112	6	4	2	0	8.6	5.8	8	0	8	0	5	12	11	7	32	10	10	20
253	5	Low	female	100	5	23	30	0	36.7	14.6	9	3	12	1	3	11	7	6	29	8	7	15
255	4	Low	female	110	6	12	10	0	20.5	14.6	5	5	10	2	4	10	11	4	32	9	8	17
271	4	Low	female	103	6	6	7	0	8.4	16	8	6	14	2	4	13	10	6.5	30	8	8	16
404	0	Low	female	107	6	6	5	0	8.1	6.6	5	0	5	1	4	12	13	5.5	32	12	11	23
407	1	Low	female	105	6	14	5	0	13.8	16	10	4	14	3	4	12	9	5.5	28	7	10	17
419	3	Low	female	113	6	4	3	0	1.4	5.8	7	1	8	0	6	14	11	4	32	11	11	22
428	4	Low	female	105	6	8	15	2	15.9	10.2	6	2	8	2	4	10	10	6.5	31	10	9	19
452	2	Low	female	97	6	21	22	1	30.1	8.7	7	1	8	4	4	13	13	8	22	12	10	22
463	4	Low	female	97	6	4	2	0	8.6	12.4	8	2	10	2	7	8	10	8	31	9	8	17
469	2	Low	female	105	6	4	2	0	1.5	16	7	6	13	5	4	9	11	7.5	29	10	10	20
484	4	Low	female	90	6	5	5	1	6.2	21.9	9	10	19	2	4	8	11	4.5	28	10	8	18
486	5	Low	female	117	6	6	3	1	3.9	5.8	3	1	4	0	4	14	15	8.5	29	10	9	19
493	3	Low	female	82	6	6	7	1	8.5	13.9	6	6	12	2	3	11	11	7	31	12	9	21
526	2	Low	female	106	6	10	5	1	10.5	16	8	6	14	5	4	11	12	4.5	30	9	10	19
528	1	Low	female	97	6	8	8	0	11.8	32.1	6	10	16	11	2	9	12	6.5	32	9	9	18
531	4	Low	female	101	6	3	2	0	1.5	18.9	4	10	14	4	3	9	8	6.5	26	9	10	19
545	2	Low	female	98	6	12	11	0	19.5	10.2	8	1	9	1	6	12	8	4	29	8	8	16
547	1	Low	female	101	6	7	4	1	5.9	15.3	8	4	12	1	3	9	8	6.5	31	12	11	23
71	3	Low	male	110	3	36	20	1	41.4	52.6	3	20	23	23	4	12	9	6.5	31	7	9	16

EXPERIMENT 1A Raw Data Set

	Schizotypy				WCST					MCST					Auditory w-m		Visual w-m		Spatial w-m			
ID#	score	25%	sex	FSIQ	wcat	wpe	wnpe	wfms	wtep	mtep	mee	mre	mnpe	mpe	dsb-string	lns	vpt	cdl	sdrt	ssf	ssb	sst
122	5	Low	male	112	6	4	1	0	7.1	12.4	6	5	11	2	5	13	9	5.5	32	9	10	19
203	4	Low	male	113	6	7	6	0	9.1	16.8	7	5	12	1	6	12	8	7.5	31	6	9	15
238	4	Low	male	110	6	4	2	0	8.6	16.8	10	3	13	2	5	10	11	6.5	31	13	11	24
249	2	Low	male	111	6	3	7	2	5.5	12.4	5	2	7	4	6	14	12	9	32	13	11	24
519	3	Low	male	113	6	4	3	0	2.8	8.7	9	2	11	0	6	12	12	5	31	13	14	27
529	3	Low	male	102	6	3	3	0	1.5	6.6	9	0	9	0	4	13	15	9	31	12	12	24
544	4	Low	male	117	6	8	5	0	9.1	9.5	9	1	10	0	7	13	15	9	30	12	11	23
548	4	Low	male	102	6	4	2	0	8.6	7.3	5	1	6	2	6	13	13	7	32	11	13	24
555	1	Low	male	117	6	8	4	0	7.8	9.5	7	3	10	1	4	9	10	5	32	10	7	17

Percentage of total errors

Frequencies on WCST and MCST for each working memory task

Digit Span Backwards

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	43	43	43	43	43	43
	Missing	0	0	0	0	0	0
Mean		2.6946	3.5957	.7866	1.0788	8.4535	14.0023
Std. Error of Mean		.1685	.1598	5.697E-02	3.626E-02	1.0709	1.3564
Std. Deviation		1.1049	1.0482	.3736	.2378	7.0227	8.8946
Skewness		.724	1.164	-.335	.374	1.968	1.961
Std. Error of Skewness		.361	.361	.361	.361	.361	.361
Kurtosis		.865	1.637	-.473	.077	5.364	4.491
Std. Error of Kurtosis		.709	.709	.709	.709	.709	.709
Range		4.87	4.79	1.42	1.03	35.30	43.00

Letter Number Span

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	39	39	39	39	39	39
	Missing	0	0	0	0	0	0
Mean		2.5834	3.6163	.7506	1.0839	7.7410	14.184
Std. Error of Mean		.1676	.1707	5.979E-02	3.770E-02	.9953	1.4710
Std. Deviation		1.0464	1.0661	.3734	.2354	6.2158	9.1866
Skewness		.600	1.257	-.353	.592	1.734	1.944
Std. Error of Skewness		.378	.378	.378	.378	.378	.378
Kurtosis		.497	1.559	-.661	-.015	3.893	4.132
Std. Error of Kurtosis		.741	.741	.741	.741	.741	.741
Range		4.30	4.63	1.33	.97	28.70	42.30

Visual Patterns Test

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	34	34	34	34	34	34
	Missing	0	0	0	0	0	0
Mean		2.8095	3.4156	.8089	1.0353	9.3882	12.6559
Std. Error of Mean		.2128	.1731	7.051E-02	3.966E-02	1.3976	1.4782
Std. Deviation		1.2410	1.0096	.4111	.2313	8.1491	8.6196
Skewness		.633	1.631	-.368	.657	1.732	2.624
Std. Error of Skewness		.403	.403	.403	.403	.403	.403
Kurtosis		.390	3.813	-.677	.877	3.486	8.390
Std. Error of Kurtosis		.788	.788	.788	.788	.788	.788
Range		4.87	4.79	1.42	1.03	35.30	43.00

Spatial Delayed Response Task

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	41	41	41	41	41	41
	Missing	0	0	0	0	0	0
Mean		2.8241	3.4386	.8428	1.0486	9.0000	12.5341
Std. Error of Mean		.1601	.1333	5.207E-02	3.201E-02	1.0156	1.0422
Std. Deviation		1.0249	.8533	.3334	.2050	6.5030	6.6733
Skewness		.565	1.044	-.468	.349	1.437	1.768
Std. Error of Skewness		.369	.369	.369	.369	.369	.369
Kurtosis		.260	1.419	.114	.102	2.012	3.835
Std. Error of Kurtosis		.724	.724	.724	.724	.724	.724
Range		4.30	3.89	1.33	.91	28.70	31.40

Spatial Span Forwards

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	38	38	38	38	38	38
	Missing	0	0	0	0	0	0
Mean		2.9712	3.6033	.8716	1.0803	10.3211	14.0842
Std. Error of Mean		.2009	.1725	6.061E-02	3.884E-02	1.4697	1.5118
Std. Deviation		1.2384	1.0631	.3736	.2394	9.0599	9.3193
Skewness		.975	1.371	-.399	.324	2.079	2.445
Std. Error of Skewness		.383	.383	.383	.383	.383	.383
Kurtosis		1.431	3.084	.284	.605	4.501	7.699
Std. Error of Kurtosis		.750	.750	.750	.750	.750	.750
Range		5.25	5.15	1.47	1.08	40.00	48.20

Spatial Span Backwards

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	40	40	40	40	40	40
	Missing	0	0	0	0	0	0
Mean		2.7158	3.4487	.7982	1.0452	8.5550	12.7450
Std. Error of Mean		.1739	.1477	5.665E-02	3.653E-02	1.1365	1.1274
Std. Deviation		1.0999	.9344	.3583	.2310	7.1880	7.1301
Skewness		.873	.714	-.228	.104	2.015	1.420
Std. Error of Skewness		.374	.374	.374	.374	.374	.374
Kurtosis		1.077	.434	-.262	-.559	5.194	2.535
Std. Error of Kurtosis		.733	.733	.733	.733	.733	.733
Range		4.87	3.89	1.42	.91	35.30	31.40

Spatial Span Total

		SQWTEP	SQMTEP	WTEPLOG	MTEPLOG	WTEP	MTEP
N	Valid	36	36	36	36	36	36
	Missing	0	0	0	0	0	0
Mean		2.9098	3.5152	.8434	1.0536	10.0944	13.5917
Std. Error of Mean		.2156	.1879	6.629E-02	4.268E-02	1.5609	1.6301
Std. Deviation		1.2937	1.1272	.3978	.2561	9.3652	9.7808
Skewness		.971	1.389	-.321	.470	2.047	2.363
Std. Error of Skewness		.393	.393	.393	.393	.393	.393
Kurtosis		1.229	2.625	-.108	.251	4.218	6.914
Std. Error of Kurtosis		.768	.768	.768	.768	.768	.768
Range		5.25	5.15	1.47	1.08	40.00	48.20

2 [group: high scorers, low scorers] x 2 (CST: Wisconsin, Madrid) ANOVAs for each working memory task – logarithm transformed

<u>NB</u> Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	1.643	1	1.643	29.466	.000	.418	1.000
FEEDBACK * DSBSC	.114	1	.114	2.042	.161	.047	.287
Error(FEEDBACK)	2.287	41	5.577E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	71.823	1	71.823	516.220	.000	.926	1.000
DSBSC	.131	1	.131	.944	.337	.023	.158
Error	5.704	41	.139				

a Computed using alpha = .05

Letter Number span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2.325	1	2.325	30.103	.000	.449	1.000
FEEDBACK * LNSSC	.255	1	.255	3.307	.077	.082	.425
Error(FEEDBACK)	2.857	37	7.722E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	65.632	1	65.632	604.864	.000	.942	1.000
LNSSC	.277	1	.277	2.549	.119	.064	.343
Error	4.015	37	.109				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.901	1	.901	10.270	.003	.243	.874
FEEDBACK * VPTMAXSC	8.602E-02	1	8.602E-02	.980	.330	.030	.161
Error(FEEDBACK)	2.808	32	8.775E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	58.227	1	58.227	467.319	.000	.936	1.000
VPTMAXSC	.462	1	.462	3.708	.063	.104	.463
Error	3.987	32	.125				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.864	1	.864	13.866	.001	.262	.953
FEEDBACK * SDRTSC	2.945E-02	1	2.945E-02	.472	.496	.012	.103
Error(FEEDBACK)	2.431	39	6.234E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	66.578	1	66.578	764.219	.000	.951	1.000
SDRTSC	.269	1	.269	3.083	.087	.073	.402
Error	3.398	39	8.712E-02				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.792	1	.792	12.102	.001	.252	.923
FEEDBACK * SSFSC	1.989E-02	1	1.989E-02	.304	.585	.008	.084
Error(FEEDBACK)	2.355	36	6.542E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	70.965	1	70.965	533.553	.000	.937	1.000
SSFSC	.122	1	.122	.917	.345	.025	.154
Error	4.788	36	.133				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	1.240	1	1.240	17.440	.000	.315	.983
FEEDBACK * SSBSC	3.100E-02	1	3.100E-02	.436	.513	.011	.099
Error(FEEDBACK)	2.703	38	7.112E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	59.692	1	59.692	686.167	.000	.948	1.000
SSBSC	1.048	1	1.048	12.050	.001	.241	.923
Error	3.306	38	8.699E-02				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.781	1	.781	12.023	.001	.261	.920
FEEDBACK * SSTSC	1.433E-02	1	1.433E-02	.221	.642	.006	.074
Error(FEEDBACK)	2.208	34	6.493E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	65.265	1	65.265	442.011	.000	.929	1.000
SSTSC	.591	1	.591	4.001	.054	.105	.493
Error	5.020	34	.148				

a Computed using alpha = .05

One-way ANOVAs for Letter Number Span- logarithm transformed

MCST

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.532	1	.532	12.499	.001
Within Groups	1.574	37	4.255E-02		
Total	2.106	38			

WCST

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.115E-04	1	2.115E-04	.001	.970
Within Groups	5.298	37	.143		
Total	5.298	38			

For low scorers

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	1.826	1	1.826	21.970	.000	.579	.992
Error(FEEDBACK)	1.330	16	8.313E-02				

a Computed using alpha = .05

For high scorers

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.596	1	.596	8.194	.009	.281	.779
Error(FEEDBACK)	1.527	21	7.272E-02				

a Computed using alpha = .05

One-way ANOVAs for group on WCST and MCST for each remaining working memory task - logarithm transformed

Digit Span Backwards

Descriptives

		N	Mean	Std. Deviation	Std. Error
WTEP	low	25	9.1280	8.2194	1.6439
	high	18	7.5167	4.9868	1.1754
	Total	43	8.4535	7.0227	1.0709
MTEP	low	25	16.5360	10.5423	2.1085
	high	18	10.4833	4.0005	.9429
	Total	43	14.0023	8.8946	1.3564

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WTEPLOG	Between Groups	3.116E-04	1	3.116E-04	.002	.963
	Within Groups	5.862	41	.143		
	Total	5.862	42			
MTEPLOG	Between Groups	.245	1	.245	4.716	.036
	Within Groups	2.129	41	5.193E-02		
	Total	2.374	42			

Visual Patterns Test

Descriptives

		N	Mean	Std. Deviation	Std. Error
WTEP	low	16	11.0125	9.3896	2.3474
	high	18	7.9444	6.8138	1.6060
	Total	34	9.3882	8.1491	1.3976
MTEP	low	16	16.9125	10.7689	2.6922
	high	18	8.8722	3.1124	.7336
	Total	34	12.6559	8.6196	1.4782

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WTEPLOG	Between Groups	7.467E-02	1	7.467E-02	.434	.515
	Within Groups	5.504	32	.172		
	Total	5.578	33			
MTEPLOG	Between Groups	.473	1	.473	11.728	.002
	Within Groups	1.292	32	4.036E-02		
	Total	1.765	33			

Spatial Delayed Response Task

Descriptives

		N	Mean	Std. Deviation	Std. Error
WTEP	low	13	11.1615	8.7878	2.4373
	high	28	7.9964	5.0034	.9456
	Total	41	9.0000	6.5030	1.0156
MTEP	low	13	15.6385	7.3122	2.0280
	high	28	11.0929	5.9512	1.1247
	Total	41	12.5341	6.6733	1.0422

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WTEPLOG	Between Groups	6.009E-02	1	6.009E-02	.534	.469
	Within Groups	4.386	39	.112		
	Total	4.446	40			
MTEPLOG	Between Groups	.238	1	.238	6.434	.015
	Within Groups	1.442	39	3.699E-02		
	Total	1.680	40			

Spatial Span Forwards

Descriptives

		N	Mean	Std. Deviation	Std. Error
WTEP	1	21	11.7762	10.7051	2.3361
	3	17	8.5235	6.3524	1.5407
	Total	38	10.3211	9.0599	1.4697
MTEP	1	21	16.3571	11.4774	2.5046
	3	17	11.2765	4.5846	1.1119
	Total	38	14.0842	9.3193	1.5118

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WTEPLOG	Between Groups	2.169E-02	1	2.169E-02	.152	.699
	Within Groups	5.143	36	.143		
	Total	5.165	37			
MTEPLOG	Between Groups	.120	1	.120	2.163	.150
	Within Groups	2.000	36	5.557E-02		
	Total	2.121	37			

Spatial Span Backwards

Descriptives

		N	Mean	Std. Deviation	Std. Error
WTEP	1	25	10.6400	8.1992	1.6398
	3	15	5.0800	2.8252	.7295
	Total	40	8.5550	7.1880	1.1365
MTEP	1	25	14.9920	7.7976	1.5595
	3	15	9.0000	3.6532	.9432
	Total	40	12.7450	7.1301	1.1274

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WTEPLOG	Between Groups	.720	1	.720	6.383	.016
	Within Groups	4.286	38	.113		
	Total	5.006	39			
MTEPLOG	Between Groups	.359	1	.359	7.928	.008
	Within Groups	1.723	38	4.533E-02		
	Total	2.082	39			

Spatial Span Total

Descriptives

		N	Mean	Std. Deviation	Std. Error
WTEP	low	17	13.3059	11.3242	2.7465
	high	19	7.2211	6.1722	1.4160
	Total	36	10.0944	9.3652	1.5609
MTEP	low	17	17.0765	12.6829	3.0761
	high	19	10.4737	4.6153	1.0588
	Total	36	13.5917	9.7808	1.6301

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
WTEPLOG	Between Groups	.395	1	.395	2.608	.116
	Within Groups	5.143	34	.151		
	Total	5.537	35			
MTEPLOG	Between Groups	.211	1	.211	3.433	.073
	Within Groups	2.085	34	6.132E-02		
	Total	2.295	35			

Perseverative and nonperseverative errors

Frequencies on WCST and MCST for each working memory task

WCST

	SQWPE	WPELOG	WPE	SQWNPE	WNPELOG	WNPE
N	90	90	90	90	90	90
	0	0	0	0	0	0
Mean	2.6037	.8067	7.24	2.3161	.6799	6.06
Std. Error of Mean	7.228E-02	2.104E-02	.49	8.813E-02	3.069E-02	.52
Std. Deviation	.6857	.1996	4.64	.8361	.2911	4.97
Skewness	2.102	.959	3.569	1.420	.225	2.547
Std. Error of Skewness	.254	.254	.254	.254	.254	.254
Kurtosis	7.056	1.794	17.603	2.742	.505	7.718
Std. Error of Kurtosis	.503	.503	.503	.503	.503	.503

MCST

	SQMNPE	MNPELOG	MNPE +constant(1)	SQMPE	MPELOG	MPE + constant (1)
N	90	90	90	90	90	90
	0	0	0	0	0	0
Mean	3.3614	1.0346	11.71	1.7716	.4344	3.69
Std. Error of Mean	6.802E-02	2.006E-02	.45	7.862E-02	3.384E-02	.40
Std. Deviation	.6453	.1903	4.26	.7459	.3210	3.83
Skewness	-.333	-1.852	.393	1.910	.493	3.581
Std. Error of Skewness	.254	.254	.254	.254	.254	.254
Kurtosis	1.009	8.567	.092	5.445	.319	15.560
Std. Error of Kurtosis	.503	.503	.503	.503	.503	.503

2 [group: high scorers, low scorers] x 2 (error type: perseverative, nonperseverative) ANOVAs for WCST for each working memory task – logarithm transformed

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.139	1	.139	12.732	.001	.237	.936
ERRORTYP * DSBSC	1.363E-03	1	1.363E-03	.125	.726	.003	.064
Error(ERRORTYP)	.447	41	1.091E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	45.999	1	45.999	489.111	.000	.923	1.000
DSBSC	.180	1	.180	1.911	.174	.045	.271
Error	3.856	41	9.405E-02				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects
Measure: MEASURE_1
Sphericity Assumed

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.304	1	.304	19.267	.000	.342	.990
ERRORTYP * LNSSC	5.590E-03	1	5.590E-03	.355	.555	.009	.089
Error(ERRORTYP)	.583	37	1.576E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	37.727	1	37.727	367.091	.000	.908	1.000
LNSSC	2.952E-02	1	2.952E-02	.287	.595	.008	.082
Error	3.803	37	.103				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.264	1	.264	22.108	.000	.409	.995
ERRORTYP * VPTMAXSC	1.122E-02	1	1.122E-02	.939	.340	.029	.156
Error(ERRORTYP)	.382	32	1.194E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	40.039	1	40.039	353.915	.000	.917	1.000
VPTMAXSC	.222	1	.222	1.962	.171	.058	.274
Error	3.620	32	.113				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.226	1	.226	8.622	.006	.181	.817
ERRORTYP * SDRTSC	2.313E-03	1	2.313E-03	.088	.768	.002	.060
Error(ERRORTYP)	1.023	39	2.623E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	41.124	1	41.124	424.842	.000	.916	1.000
SDRTSC	.386	1	.386	3.987	.053	.093	.495
Error	3.775	39	9.680E-02				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.120	1	.120	9.966	.003	.217	.867
ERRORTYP * SSFSC	5.512E-03	1	5.512E-03	.458	.503	.013	.101
Error(ERRORTYP)	.433	36	1.203E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	48.294	1	48.294	457.797	.000	.927	1.000
SSFSC	.180	1	.180	1.708	.200	.045	.246
Error	3.798	36	.105				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.453	1	.453	20.203	.000	.347	.992
ERRORTYP * SSBSC	2.916E-05	1	2.916E-05	.001	.971	.000	.050
Error(ERRORTYP)	.852	38	2.242E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	37.538	1	37.538	466.743	.000	.925	1.000
SSBSC	.828	1	.828	10.296	.003	.213	.878
Error	3.056	38	8.043E-02				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.110	1	.110	10.403	.003	.234	.880
ERRORTYP * SSTSC	1.627E-04	1	1.627E-04	.015	.902	.000	.052
Error(ERRORTYP)	.360	34	1.060E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	45.559	1	45.559	431.561	.000	.927	1.000
SSTSC	.715	1	.715	6.775	.014	.166	.715
Error	3.589	34	.106				

a Computed using alpha = .05

2 [group: high scorers, low scorers] x 2 (error type: perseverative, nonperseverative) ANOVAs for MCST for each working memory task – logarithm transformed

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	8.458	1	8.458	188.456	.000	.821	1.000
ERRORTYP * DSBSC	3.487E-02	1	3.487E-02	.777	.383	.019	.138
Error(ERRORTYP)	1.840	41	4.488E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	43.327	1	43.327	356.263	.000	.897	1.000
DSBSC	.198	1	.198	1.625	.210	.038	.238
Error	4.986	41	.122				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	7.374	1	7.374	168.408	.000	.820	1.000
ERRORTYP * LNSSC	5.807E-02	1	5.807E-02	1.326	.257	.035	.202
Error(ERRORTYP)	1.620	37	4.379E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	45.817	1	45.817	530.170	.000	.935	1.000
LNSSC	.641	1	.641	7.412	.010	.167	.755
Error	3.197	37	8.642E-02				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	5.139	1	5.139	102.635	.000	.762	1.000
ERRORTYP * VPTMAXSC	4.579E-03	1	4.579E-03	.091	.764	.003	.060
Error(ERRORTYP)	1.602	32	5.007E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	34.553	1	34.553	353.690	.000	.917	1.000
VPTMAXSC	.758	1	.758	7.756	.009	.195	.771
Error	3.126	32	9.769E-02				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	6.138	1	6.138	220.870	.000	.850	1.000
ERRORTYP * SDRTSC	2.288E-02	1	2.288E-02	.823	.370	.021	.143
Error(ERRORTYP)	1.084	39	2.779E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	42.110	1	42.110	717.722	.000	.948	1.000
SDRTSC	.350	1	.350	5.966	.019	.133	.664
Error	2.288	39	5.867E-02				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	7.784	1	7.784	185.510	.000	.837	1.000
ERRORTYP * SSFSC	1.304E-03	1	1.304E-03	.031	.861	.001	.053
Error(ERRORTYP)	1.511	36	4.196E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	41.331	1	41.331	454.890	.000	.927	1.000
SSFSC	.109	1	.109	1.197	.281	.032	.187
Error	3.271	36	9.086E-02				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	7.905	1	7.905	215.652	.000	.850	1.000
ERRORTYP * SSBSC	4.892E-02	1	4.892E-02	1.334	.255	.034	.203
Error(ERRORTYP)	1.393	38	3.666E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	37.202	1	37.202	619.480	.000	.942	1.000
SSBSC	.521	1	.521	8.674	.005	.186	.819
Error	2.282	38	6.005E-02				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	7.226	1	7.226	186.852	.000	.846	1.000
ERRORTYP * SSTSC	3.309E-03	1	3.309E-03	.086	.772	.003	.059
Error(ERRORTYP)	1.315	34	3.867E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	38.103	1	38.103	386.804	.000	.919	1.000
SSTSC	.199	1	.199	2.023	.164	.056	.282
Error	3.349	34	9.851E-02				

a Computed using alpha = .05

APPENDIX B

Key to Raw Data

wtep	WCST percentage of total errors
weep	WCST percentage of efficient errors
wrep	WCST percentage of random errors
wpep	WCST percentage of perseverative errors
wrpp	WCST percentage of total errors (excluding efficient errors)
mtep	MCST percentage of total errors
meep	MCST percentage of efficient errors
mrep	MCST percentage of random errors
mpep	MCST percentage of perseverative errors
mrpp	MCST percentage of total errors (excluding efficient errors)

All working memory tasks categorised as: 1=low; 2=medium; 3=high

dsbcat	Digit Span Backwards category
lnscat	Letter Number Span category
vptcat	Visual Patterns Test category
sdrtcat	Spatial Delayed Response Task category
ssfcat	Spatial Span Forwards category
ssbcat	Spatial Span Backwards category
sstcat	Spatial Span Total category

EXPERIMENT 1B Raw Data Set

	rWCST					MCST					Auditory w-m		Visual w-m		Spatial w-m		
ID#	wtep	weep	wrep	wpep	wrpp	mtep	meep	mrep	mpep	mrpp	dsbcat	lnscat	vptcat	sdrtcat	ssfcat	ssbcat	sstcat
21	2.8	2.8	0	0	0	5.1	5.1	0	0	0	1	1	2	2	1	2	2
29	8.5	4.3	2.1	2.1	4.2	10.9	5.8	4.4	0.7	5.1	3	2	2	1	2	2	2
33	2.8	2.8	0	0	0	4.4	2.2	2.2	0	2.2	2	2	3	3	2	3	3
38	6.4	2.1	4.3	0	4.3	9.5	7.3	1.5	0.7	2.2	1	2	3	3	3	2	3
47	19.1	4.3	10.6	4.3	14.9	10.9	4.3	4.4	2.2	6.6	2	2	2	2	1	2	1
50	8.5	2.1	4.3	2.1	6.4	5.1	1.6	2	1.5	3.5	3	2	2	2	2	1	2
52	2.8	2.8	0	0	0	5.1	4.4	0.7	0	0.7	3	2	2	2	2	2	2
59	11.4	9.1	2.3	0	2.3	16.8	4.4	8	4.4	12.4	2	2	3	2	3	2	3
62	5.1	2.6	2.6	0	2.6	14.6	4.4	5.8	4.4	10.2	1	2	2	3	2	1	2
71	52.3	1.6	11.5	49.2	60.7	52.6	2.2	28.5	21.9	50.4	2	2	2	2	1	2	1
93	0	0	0	0	0	10.9	4.4	5.8	0.7	6.5	3	2	2	1	3	2	3
95	5.4	0	0	5.4	5.4	6.6	3.7	2.2	0.7	2.9	2	2	2	3	2	3	2
106	4.4	0	2.2	2.2	4.4	10.2	6.6	3.6	0	3.6	2	2	2	2	2	2	2
121	16.7	4.2	6.3	6.3	12.6	10.9	6.6	2.9	0.7	3.6	1	2	2	1	2	2	2
122	0	0	0	0	0	12.4	4.4	5.8	2.2	8	2	3	2	3	2	2	2
130	5.4	5.4	0	0	0	10.9	5.1	2.9	2.9	5.8	2	3	2	3	2	2	2
138	17.2	1.7	6.9	8.6	15.5	22.6	5.8	11.7	5.1	16.8	1	2	2	2	2	1	1
159	14	2	6	6	12	15.3	3.6	8.8	2.9	11.7	1	2	1	2	2	2	2
168	9.8	1.9	3.9	3.9	7.8	10.9	5	4.4	1.5	5.9	2	2	2	3	2	2	2
169	2.4	0	2.4	0	2.4	13.1	1.3	8.8	3	11.8	2	2	2	2	2	1	2
170	8.2	2	4.1	2	4.1	9.5	5	1.5	3	4.5	3	2	3	2	2	3	3
173	4.6	2.3	2.3	0	2.3	8.7	2.9	5.1	0.7	5.8	3	3	3	3	3	3	3
178	0	0	0	0	0	8	5	1.5	1.5	3	2	3	3	3	2	2	2
194	2.3	2.3	0	0	0	20.4	5.8	10.9	3.7	14.6	2	1	2	2	2	1	2
198	7.9	0	2.6	5.3	7.9	12.4	6.6	5.1	0.7	5.8	2	2	2	2	2	1	2
199	19.6	2.2	8.7	8.7	17.4	47.4	2.2	17.5	27.7	45.2	1	1	1	2	2	2	2
203	11.1	2.2	6.7	2.2	8.9	16.8	8.8	5.8	2.2	8	3	2	1	2	1	2	1

EXPERIMENT 1B Raw Data Set

	rWCST					MCST					Auditory w-m		Visual w-m		Spatial w-m		
ID#	wtep	weep	wrep	wpep	wrpp	mtep	meep	mrep	mpep	mrpp	dsbcat	lnscat	vptcat	sdrtcat	ssfcat	ssbcat	sstcat
220	9.3	0	6.9	2.3	9.2	5.1	4.4	0	0.7	0.7	2	2	2	3	3	3	3
222	22.2	1.9	9.3	11.1	20.4	5.8	3.6	0.7	1.5	2.2	2	3	3	2	3	1	2
226	0	0	0	0	0	11.7	5.9	2.9	5.8	8.7	2	2	2	2	2	2	2
236	33.3	1.9	19.6	11.8	31.4	20.4	8.7	8	3.7	11.7	1	2	2	1	2	1	2
238	0	0	0	0	0	16.8	7.3	7.3	2.2	9.5	2	2	2	2	3	3	3
241	13.6	6.8	4.5	2.3	6.8	21.1	5.8	9.5	5.8	15.3	2	2	1	2	3	2	3
249	8.3	4.2	2.1	2.1	4.2	12.4	3.7	5.8	2.9	8.7	3	3	2	3	3	3	3
250	15.5	6.7	6.7	2.2	8.9	8.7	7.2	1.5	0	1.5	1	2	2	3	1	2	2
252	0	0	0	0	0	5.8	5.8	0	0	0	2	2	2	3	2	2	2
253	50	3.6	23.8	22.6	46.4	14.6	6.5	6.6	1.5	8.1	1	2	1	2	1	1	1
255	26.8	7.1	8.9	10.7	19.6	14.6	3.7	8	2.9	10.9	2	2	2	3	2	1	2
260	2.8	2.8	0	0	0	12.4	5.8	5.1	1.5	6.6	2	3	1	2	1	2	1
263	17.4	6.5	8.7	2.2	10.9	4.4	3.7	0	0.7	0.7	2	2	2	2	1	1	1
270	14	2	10	2	12	15.3	8	5.1	2.2	7.3	3	2	2	2	3	2	3
271	11.4	4.5	2.3	4.5	6.8	16	5.8	6.6	3.6	10.2	2	3	2	2	1	1	1
273	14.9	2.1	10.6	2.1	12.7	5.8	5.1	0.7	0	0.7	1	2	2	2	2	1	1
283	2.8	2.8	0	0	0	4.4	4.4	0	0	0	1	2	1	2	1	2	1
304	13.7	0	5.9	7.8	13.7	5.8	2.8	1.5	1.5	3	2	2	3	2	2	2	2
307	4.7	0	2.3	2.3	4.6	22.6	8	8.8	5.8	14.6	2	2	2	3	1	2	2
404	14.3	4.7	2.4	7.1	9.5	6.6	3.7	2.2	0.7	2.9	2	2	3	3	3	3	3
407	16.3	2	10.2	4.1	14.3	16	7.3	5.1	3.6	8.7	2	2	2	1	1	2	2
415	16.3	6.9	6.9	2.3	9.2	13.1	5.8	4.4	2.9	7.3	2	2	2	2	1	2	2
416	7.5	2.5	5	0	5	11.7	8.1	2.9	0.7	3.6	2	3	2	2	2	3	2
419	2.8	2.8	0	0	0	5.8	5.1	0.7	0	0.7	3	3	2	3	2	3	3
421	13.6	6.8	2.3	4.5	6.8	12.4	2.9	8.8	0.7	9.5	2	1	1	1	1	1	1
428	22.2	4.8	14.3	3.2	17.5	10.2	5.8	2.9	1.5	4.4	2	2	2	2	2	2	2
432	9.3	4.6	2.3	2.3	4.6	11.7	4.4	7.3	0	7.3	2	3	3	2	1	2	2

EXPERIMENT 1B Raw Data Set

	rWCST					MCST					Auditory w-m		Visual w-m		Spatial w-m		
ID#	wtep	weep	wrep	wpep	wrpp	mtep	meep	mrep	mpep	mrpp	dsbcat	lnscat	vptcat	sdrtcat	ssfcat	ssbcat	sstcat
441	0	0	0	0	0	17.5	8	8	1.5	9.5	1	1	1	2	1	1	1
452	38.2	1.5	17.6	19.1	36.7	8.7	5.1	0.7	2.9	3.6	2	3	3	1	3	2	3
456	21	3.5	10.5	7	17.5	6.6	5.2	0.7	0.7	1.4	2	1	1	3	2	2	2
463	0	0	0	0	0	12.4	5.8	5.1	1.5	6.6	3	1	2	2	2	1	2
469	3	0	0	3	3	16	5.1	7.3	3.6	10.9	2	1	2	2	2	2	2
474	8.9	4.4	0	4.4	4.4	8.7	4.3	4.4	0	4.4	1	1	2	2	2	2	2
479	9.4	0	7.5	1.9	9.4	32.8	6.5	14.6	11.7	26.3	1	1	2	2	1	1	1
480	26.5	1.5	17.6	7.4	25	18.9	5	8.8	5.1	13.9	3	3	2	2	2	2	2
484	8.9	2.2	2.2	4.4	6.6	21.9	6.6	12.4	2.9	15.3	2	1	2	1	2	1	2
486	6.8	2.3	2.3	2.3	4.6	5.8	2.1	3.7	0	3.7	2	3	3	2	2	2	2
490	12.1	1.7	6.9	3.4	10.3	10.2	5.1	1.5	3.6	5.1	2	2	1	2	2	1	2
491	10.3	0	5.1	5.1	10.2	14.6	7.3	5.1	2.2	7.3	3	3	2	3	2	2	2
493	11.4	2.3	6.8	2.3	9.1	13.9	4.4	7.3	2.2	9.5	1	2	2	2	3	2	2
496	8.5	0	6.4	2.1	8.5	8	4.4	2.9	0.7	3.6	1	3	2	2	2	1	1
498	0	0	0	0	0	6.6	3	3.6	0	3.6	3	3	2	3	2	2	2
510	6.5	2.2	4.3	0	4.3	12.4	5.1	5.1	2.2	7.3	2	2	2	1	1	2	2
517	10.4	6.3	4.2	0	4.2	17.5	3.6	7.3	6.6	13.9	1	1	2	3	2	1	2
518	10.9	6.5	2.2	2.2	4.4	8.7	5	3.7	0	3.7	2	3	2	3	2	2	2
519	2.8	2.8	0	0	0	8.7	6.5	2.2	0	2.2	3	2	2	2	3	3	3
526	14.9	0	6.4	8.5	14.9	16	5.7	6.6	3.7	10.3	2	2	2	2	2	2	2
528	14.3	2	6.1	6.1	12.2	32.1	4.4	13.1	14.6	27.7	1	1	2	3	2	2	2
529	3	3	0	0	0	6.6	6.6	0	0	0	2	3	3	2	3	3	3
531	3	3	0	0	0	18.9	2.9	10.9	5.1	16	1	1	1	1	2	2	2
539	3.7	0	3.7	0	3.7	16.8	8.8	5.8	2.2	8	2	2	2	3	2	1	2
541	30	3.3	15	11.7	26.7	10.2	4.3	4.4	1.5	5.9	2	2	2	3	2	2	2
544	13.9	4.6	4.6	4.6	9.2	9.5	6.6	2.9	0	2.9	3	3	3	2	3	3	3
545	28.6	5.4	14.3	8.9	23.2	10.2	9.5	3.7	0.7	4.4	3	2	1	2	1	1	1

EXPERIMENT 1B Raw Data Set

ID#	rWCST wtep	weep	wrep	wpep	wrpp	MCST mtep	meep	mrep	mpep	mrpp	Auditory w-m dsbcat	lnscat	Visual w-m vptcat	sdrtcat	Spatial w-m ssfcat	ssbcat	sstcat
546	10	2	6	2	8	11.7	2.9	5.1	3.7	8.8	2	2	1	1	2	2	2
547	8.8	0	4.4	4.4	8.8	15.3	5.8	7.3	2.2	9.5	1	1	1	2	3	3	3
548	0	0	0	0	0	7.3	2.9	2.2	2.2	4.4	3	3	3	3	2	3	3
550	33.3	4.2	10.4	18.8	29.2	35.8	2.9	18.3	14.6	32.9	1	1	1	1	1	1	1
555	8.7	2.2	2.2	4.3	6.5	9.5	5.1	2.9	1.5	4.4	2	1	2	3	2	1	2
556	2.8	0	0	2.8	2.8	9.5	7.3	1.5	0.7	2.2	1	2	3	2	2	2	2
559	2.8	2.8	0	0	0	12.4	6.6	2.9	2.9	5.8	1	3	3	1	2	2	2
572	17.9	5.8	10.7	1.8	12.5	13.1	3.6	5.8	3.7	9.5	2	2	3	3	1	2	1
576	5.5		0	0	0	11.7	7.3	3.7	0.7	4.4	1	2	2	2	2	2	2

Frequencies

WCST variables

	SQWTEP	WTEPLOG	WTEP	SQWEEP	WEEPLOG	WEEP	SQWREP	WREPLOG	WREP	SQWPEP	WPEPLOG	WPEP	SQWRPP	WRPPLOG	WRPP
N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	3.2033	.9166	11.2056	1.7888	.4525	2.5522	2.1848	.5780	4.8022	1.9628	.4809	3.9589	2.7530	.7456	8.7389
Std. Deviation	1.4021	.4320	10.3603	.5970	.3126	2.2016	1.0200	.4319	5.0932	1.0576	.4202	6.5297	1.4778	.5050	10.4248
Skewness	.521	-.708	1.750	.099	-.378	.667	.494	-.180	1.368	1.821	.347	4.372	.840	-.306	2.405
Std. Error of Skewness	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254
Kurtosis	.349	.087	3.943	-.882	-1.121	-.142	-.463	-1.261	1.977	5.534	-.579	26.211	.928	-.956	7.862
Std. Error of Kurtosis	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503

SQ=square root; LOG=logarithm

Frequencies

MCST variables

	SQMTEP	MTEPLOG	MTEP	SQMEEP	MEEPLOG	MEEP	SQMREP	MREPLOG	MREP	SQMPEP	MPEPLOG	MPEP	SQMRPP	MRPPLOG	MRPP
N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	3.5059	1.0602	13.2189	2.2372	.6839	5.1678	2.3681	.6944	5.2856	1.7920	.4411	2.8311	2.7981	.8257	8.1167
Std. Deviation	.9686	.2234	8.2192	.4058	.1696	1.7763	.8278	.3171	4.5283	.7918	.3259	4.2980	1.1409	.3504	8.3868
Skewness	1.376	.385	2.514	-.327	-.886	.143	.698	-.417	2.110	2.119	.641	3.744	1.312	-.255	2.934
Std. Error of Skewness	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254	.254
Kurtosis	3.170	.480	8.507	-.117	.951	-.354	1.303	.022	7.472	6.251	.610	16.665	3.162	.494	10.973
Std. Error of Kurtosis	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503	.503

SQ=square root; LOG=logarithm

Percentage of total errors

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.722	1	.722	8.765	.005	.176	.824
CST * DSBSC	3.181E-02	1	3.181E-02	.386	.538	.009	.093
Error(CST)	3.380	41	8.243E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	79.331	1	79.331	518.918	.000	.927	1.000
DSBSC	.771	1	.771	5.045	.030	.110	.592
Error	6.268	41	.153				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	1.338	1	1.338	13.215	.001	.263	.943
CST * LNSSC	.114	1	.114	1.122	.296	.029	.178
Error(CST)	3.746	37	.101				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	71.728	1	71.728	486.274	.000	.929	1.000
LNSSC	.482	1	.482	3.268	.079	.081	.421
Error	5.458	37	.148				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.107	1	.107	1.084	.306	.033	.173
CST * VPTMAXSC	1.201E-02	1	1.201E-02	.122	.730	.004	.063
Error(CST)	3.161	32	9.878E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	68.107	1	68.107	535.051	.000	.944	1.000
VPTMAXSC	.746	1	.746	5.857	.021	.155	.651
Error	4.073	32	.127				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.422	1	.422	4.422	.042	.102	.536
CST * SDRTSC	9.807E-03	1	9.807E-03	.103	.750	.003	.061
Error(CST)	3.723	39	9.546E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	71.225	1	71.225	487.554	.000	.926	1.000
SDRTSC	.622	1	.622	4.261	.046	.098	.521
Error	5.697	39	.146				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.103	1	.103	1.011	.321	.027	.165
CST * SSFSC	1.184E-02	1	1.184E-02	.116	.735	.003	.063
Error(CST)	3.674	36	.102				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	80.867	1	80.867	619.445	.000	.945	1.000
SSFSC	.359	1	.359	2.750	.106	.071	.365
Error	4.700	36	.131				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.355	1	.355	3.207	.081	.078	.415
CST * SSBSC	3.636E-02	1	3.636E-02	.329	.570	.009	.087
Error(CST)	4.200	38	.111				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	67.969	1	67.969	674.403	.000	.947	1.000
SSBSC	1.078	1	1.078	10.700	.002	.220	.890
Error	3.830	38	.101				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.145	1	.145	1.390	.247	.039	.209
CST * SSTSC	.137	1	.137	1.312	.260	.037	.200
Error(CST)	3.538	34	.104				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	73.647	1	73.647	495.082	.000	.936	1.000
SSTSC	1.037	1	1.037	6.972	.012	.170	.728
Error	5.058	34	.149				

a Computed using alpha = .05

Percentage of total errors (excluding efficient errors)

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.341	1	.341	2.779	.103	.063	.370
CST * DSBSC	2.440E-02	1	2.440E-02	.199	.658	.005	.072
Error(CST)	5.026	41	.123				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	47.626	1	47.626	159.456	.000	.795	1.000
DSBSC	.684	1	.684	2.291	.138	.053	.315
Error	12.246	41	.299				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	1.245	1	1.245	8.761	.005	.191	.822
CST * LNSSC	.168	1	.168	1.183	.284	.031	.185
Error(CST)	5.259	37	.142				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	44.253	1	44.253	177.435	.000	.827	1.000
LNSSC	.948	1	.948	3.800	.059	.093	.476
Error	9.228	37	.249				

a Computed using alpha = .05

Visual Patterns test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	4.632E-02	1	4.632E-02	.300	.588	.009	.083
CST * VPTMAXSC	3.129E-02	1	3.129E-02	.203	.656	.006	.072
Error(CST)	4.940	32	.154				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	42.262	1	42.262	181.410	.000	.850	1.000
VPTMAXSC	1.157	1	1.157	4.966	.033	.134	.580
Error	7.455	32	.233				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.231	1	.231	1.687	.202	.041	.245
CST * SDRTSC	8.026E-03	1	8.026E-03	.058	.810	.001	.056
Error(CST)	5.353	39	.137				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	46.602	1	46.602	224.801	.000	.852	1.000
SDRTSC	.827	1	.827	3.989	.053	.093	.495
Error	8.085	39	.207				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	2.198E-05	1	2.198E-05	.000	.990	.000	.050
CST * SSFSC	1.762E-03	1	1.762E-03	.013	.910	.000	.051
Error(CST)	4.878	36	.135				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	50.166	1	50.166	177.584	.000	.831	1.000
SSFSC	.490	1	.490	1.736	.196	.046	.250
Error	10.170	36	.282				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	7.604E-02	1	7.604E-02	.515	.477	.013	.108
CST * SSBSC	4.445E-02	1	4.445E-02	.301	.586	.008	.083
Error(CST)	5.605	38	.148				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	41.497	1	41.497	271.708	.000	.877	1.000
SSBSC	2.537	1	2.537	16.611	.000	.304	.978
Error	5.804	38	.153				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	1.358E-02	1	1.358E-02	.095	.760	.003	.060
CST * SSTSC	.193	1	.193	1.345	.254	.038	.203
Error(CST)	4.875	34	.143				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	45.245	1	45.245	162.179	.000	.827	1.000
SSTSC	1.840	1	1.840	6.595	.015	.162	.704
Error	9.485	34	.279				

a Computed using alpha = .05

Percentage of efficient errors

<u>NB</u> Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	187.578	1	187.578	57.489	.000	.584	1.000
CST * DSBSC	.753	1	.753	.231	.634	.006	.076
Error(CST)	133.777	41	3.263				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1263.077	1	1263.077	335.810	.000	.891	1.000
DSBSC	1.326	1	1.326	.352	.556	.009	.089
Error	154.212	41	3.761				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	114.385	1	114.385	29.446	.000	.443	1.000
CST * LNSSC	9.812E-02	1	9.812E-02	.025	.875	.001	.053
Error(CST)	143.731	37	3.885				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1029.087	1	1029.087	387.633	.000	.913	1.000
LNSSC	1.199E-02	1	1.199E-02	.005	.947	.000	.050
Error	98.227	37	2.655				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	64.167	1	64.167	14.068	.001	.305	.953
CST * VPTMAXSC	.309	1	.309	.068	.796	.002	.057
Error(CST)	145.961	32	4.561				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1019.810	1	1019.810	242.805	.000	.884	1.000
VPTMAXSC	3.394	1	3.394	.808	.375	.025	.141
Error	134.404	32	4.200				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	93.818	1	93.818	19.420	.000	.332	.990
CST * SDRTSC	7.028E-02	1	7.028E-02	.015	.905	.000	.052
Error(CST)	188.408	39	4.831				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1061.265	1	1061.265	333.723	.000	.895	1.000
SDRTSC	2.031	1	2.031	.639	.429	.016	.122
Error	124.023	39	3.180				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	97.074	1	97.074	17.666	.000	.329	.983
CST * SSFSC	1.352	1	1.352	.246	.623	.007	.077
Error(CST)	197.815	36	5.495				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1409.155	1	1409.155	409.085	.000	.919	1.000
SSFSC	5.771	1	5.771	1.675	.204	.044	.243
Error	124.008	36	3.445				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	142.899	1	142.899	27.916	.000	.424	.999
CST * SSBSC	.161	1	.161	.031	.860	.001	.053
Error(CST)	194.516	38	5.119				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1048.509	1	1048.509	295.366	.000	.886	1.000
SSBSC	2.970	1	2.970	.837	.366	.022	.145
Error	134.895	38	3.550				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	94.327	1	94.327	18.255	.000	.349	.986
CST * SSTSC	.588	1	.588	.114	.738	.003	.062
Error(CST)	175.687	34	5.167				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1193.455	1	1193.455	316.915	.000	.903	1.000
SSTSC	2.133	1	2.133	.566	.457	.016	.113
Error	128.039	34	3.766				

a Computed using alpha = .05

Percentage of random errors

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	1.695	1	1.695	14.780	.000	.285	.963
CST * LNSSC	.351	1	.351	3.058	.089	.076	.399
Error(CST)	4.244	37	.115				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	27.867	1	27.867	169.796	.000	.821	1.000
LNSSC	.444	1	.444	2.704	.109	.068	.360
Error	6.072	37	.164				

a Computed using alpha = .05

One-way ANOVAs for Letter Number Span

		Sum of Squares	df	Mean Square	F	Sig.
WREPLOG	Between Groups	2.732E-03	1	2.732E-03	.014	.905
	Within Groups	6.987	37	.189		
	Total	6.990	38			
MREPLOG	Between Groups	.792	1	.792	8.799	.005
	Within Groups	3.329	37	8.999E-02		
	Total	4.121	38			

For <u>low</u> scorers

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	1.590	1	1.590	13.701	.002	.461	.935
Error(CST)	1.857	16	.116				

a Computed using alpha = .05

For <u>high</u> scorers

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.289	1	.289	2.542	.126	.108	.331
Error(CST)	2.387	21	.114				

a Computed using alpha = .05

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.451	1	.451	4.651	.037	.102	.558
CST * DSBSC	1.358E-03	1	1.358E-03	.014	.906	.000	.052
Error(CST)	3.972	41	9.688E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	33.309	1	33.309	155.159	.000	.791	1.000
DSBSC	.319	1	.319	1.488	.229	.035	.222
Error	8.802	41	.215				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	8.299E-02	1	8.299E-02	.648	.427	.020	.122
CST * VPTMAXSC	4.458E-02	1	4.458E-02	.348	.559	.011	.088
Error(CST)	4.097	32	.128				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	27.128	1	27.128	176.500	.000	.847	1.000
VPTMAXSC	1.055	1	1.055	6.862	.013	.177	.719
Error	4.918	32	.154				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.346	1	.346	3.057	.088	.073	.400
CST * SDRTSC	1.050E-02	1	1.050E-02	.093	.762	.002	.060
Error(CST)	4.409	39	.113				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	30.485	1	30.485	214.008	.000	.846	1.000
SDRTSC	.590	1	.590	4.145	.049	.096	.510
Error	5.555	39	.142				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	1.546E-02	1	1.546E-02	.117	.734	.003	.063
CST * SSFSC	2.051E-03	1	2.051E-03	.016	.901	.000	.052
Error(CST)	4.739	36	.132				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	34.369	1	34.369	193.651	.000	.843	1.000
SSFSC	.389	1	.389	2.189	.148	.057	.302
Error	6.389	36	.177				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	.211	1	.211	1.608	.212	.041	.235
CST * SSBSC	5.262E-02	1	5.262E-02	.401	.531	.010	.095
Error(CST)	4.992	38	.131				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	27.126	1	27.126	262.617	.000	.874	1.000
SSBSC	1.956	1	1.956	18.934	.000	.333	.989
Error	3.925	38	.103				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	4.410E-02	1	4.410E-02	.318	.577	.009	.085
CST * SSTSC	5.529E-02	1	5.529E-02	.398	.532	.012	.094
Error(CST)	4.722	34	.139				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	31.048	1	31.048	182.070	.000	.843	1.000
SSTSC	1.320	1	1.320	7.741	.009	.185	.771
Error	5.798	34	.171				

a Computed using alpha = .05

Percentage of perseverative errors

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	5.428E-03	1	5.428E-03	.055	.815	.001	.056
CST * DSBSC	9.343E-03	1	9.343E-03	.095	.759	.002	.060
Error(CST)	4.031	41	9.833E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	15.175	1	15.175	73.448	.000	.642	1.000
DSBSC	.671	1	.671	3.248	.079	.073	.421
Error	8.471	41	.207				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	2.565E-02	1	2.565E-02	.230	.634	.006	.075
CST * LNSSC	.115	1	.115	1.029	.317	.027	.167
Error(CST)	4.119	37	.111				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	16.258	1	16.258	86.344	.000	.700	1.000
LNSSC	.964	1	.964	5.122	.030	.122	.596
Error	6.967	37	.188				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	9.969E-02	1	9.969E-02	.810	.375	.025	.141
CST * VPTMAXSC	5.973E-03	1	5.973E-03	.049	.827	.002	.055
Error(CST)	3.938	32	.123				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	15.861	1	15.861	90.651	.000	.739	1.000
VPTMAXSC	.870	1	.870	4.972	.033	.134	.580
Error	5.599	32	.175				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	4.554E-03	1	4.554E-03	.042	.840	.001	.055
CST * SDRTSC	1.113E-02	1	1.113E-02	.102	.752	.003	.061
Error(CST)	4.273	39	.110				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	16.516	1	16.516	102.429	.000	.724	1.000
SDRTSC	.589	1	.589	3.651	.063	.086	.462
Error	6.288	39	.161				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	9.539E-02	1	9.539E-02	1.025	.318	.028	.167
CST * SSFSC	3.440E-03	1	3.440E-03	.037	.849	.001	.054
Error(CST)	3.350	36	9.305E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	16.668	1	16.668	74.587	.000	.674	1.000
SSFSC	.373	1	.373	1.669	.205	.044	.242
Error	8.045	36	.223				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	6.317E-02	1	6.317E-02	.553	.462	.014	.112
CST * SSBSC	2.018E-04	1	2.018E-04	.002	.967	.000	.050
Error(CST)	4.340	38	.114				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	13.331	1	13.331	101.982	.000	.729	1.000
SSBSC	1.404	1	1.404	10.743	.002	.220	.891
Error	4.967	38	.131				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
CST	7.805E-02	1	7.805E-02	.918	.345	.026	.154
CST * SSTSC	.127	1	.127	1.497	.230	.042	.221
Error(CST)	2.891	34	8.503E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	15.617	1	15.617	70.314	.000	.674	1.000
SSTSC	1.257	1	1.257	5.659	.023	.143	.637
Error	7.552	34	.222				

a Computed using alpha = .05

Perseverative versus random errors on WCST

<u>NB</u> Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.320	1	.320	7.175	.011	.149	.744
ERRORTYP * DSBSC	3.625E-03	1	3.625E-03	.081	.777	.002	.059
Error(ERRORTYP)	1.827	41	4.457E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	20.563	1	20.563	59.865	.000	.594	1.000
DSBSC	.439	1	.439	1.277	.265	.030	.197
Error	14.083	41	.343				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	2.754E-03	1	2.754E-03	.071	.791	.002	.058
ERRORTYP * LNSSC	8.111E-02	1	8.111E-02	2.088	.157	.053	.291
Error(ERRORTYP)	1.437	37	3.884E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	15.401	1	15.401	46.627	.000	.558	1.000
LNSSC	.129	1	.129	.390	.536	.010	.093
Error	12.222	37	.330				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	9.672E-02	1	9.672E-02	2.620	.115	.076	.349
ERRORTYP * VPTMAXSC	3.926E-04	1	3.926E-04	.011	.919	.000	.051
Error(ERRORTYP)	1.181	32	3.692E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	21.246	1	21.246	60.285	.000	.653	1.000
VPTMAXSC	.698	1	.698	1.981	.169	.058	.277
Error	11.278	32	.352				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.161	1	.161	3.033	.089	.072	.397
ERRORTYP * SDRTSC	1.070E-02	1	1.070E-02	.202	.656	.005	.072
Error(ERRORTYP)	2.068	39	5.302E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	20.543	1	20.543	67.189	.000	.633	1.000
SDRTSC	.592	1	.592	1.936	.172	.047	.274
Error	11.924	39	.306				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.453	1	.453	9.227	.004	.204	.840
ERRORTYP * SSFSC	2.081E-03	1	2.081E-03	.042	.838	.001	.055
Error(ERRORTYP)	1.769	36	4.913E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	25.653	1	25.653	78.205	.000	.685	1.000
SSFSC	.389	1	.389	1.186	.283	.032	.185
Error	11.809	36	.328				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.179	1	.179	3.167	.083	.077	.411
ERRORTYP * SSBSC	4.593E-02	1	4.593E-02	.813	.373	.021	.142
Error(ERRORTYP)	2.147	38	5.650E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	18.711	1	18.711	72.741	.000	.657	1.000
SSBSC	1.998	1	1.998	7.768	.008	.170	.775
Error	9.774	38	.257				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.320	1	.320	6.688	.014	.164	.710
ERRORTYP * SSTSC	2.199E-03	1	2.199E-03	.046	.831	.001	.055
Error(ERRORTYP)	1.625	34	4.780E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	23.008	1	23.008	71.061	.000	.676	1.000
SSTSC	2.048	1	2.048	6.324	.017	.157	.686
Error	11.008	34	.324				

a Computed using alpha = .05

Perseverative versus random errors on MCST

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

Digit Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	1.717	1	1.717	69.322	.000	.628	1.000
ERRORTYP * DSBSC	3.753E-02	1	3.753E-02	1.515	.225	.036	.225
Error(ERRORTYP)	1.016	41	2.477E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	26.340	1	26.340	129.330	.000	.759	1.000
DSBSC	.521	1	.521	2.560	.117	.059	.346
Error	8.350	41	.204				

a Computed using alpha = .05

Letter Number Span

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	1.426	1	1.426	31.815	.000	.462	1.000
ERRORTYP * LNSSC	9.674E-04	1	9.674E-04	.022	.884	.001	.052
Error(ERRORTYP)	1.659	37	4.483E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	29.016	1	29.016	176.436	.000	.827	1.000
LNSSC	1.663	1	1.663	10.111	.003	.215	.872
Error	6.085	37	.164				

a Computed using alpha = .05

Visual Patterns Test

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	.837	1	.837	17.351	.000	.352	.981
ERRORTYP * VPTMAXSC	1.300E-02	1	1.300E-02	.270	.607	.008	.080
Error(ERRORTYP)	1.543	32	4.823E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	20.992	1	20.992	147.627	.000	.822	1.000
VPTMAXSC	1.264	1	1.264	8.886	.005	.217	.824
Error	4.550	32	.142				

a Computed using alpha = .05

Spatial Delayed Response Task

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	1.116	1	1.116	37.685	.000	.491	1.000
ERRORTYP * SDRTSC	1.093E-02	1	1.093E-02	.369	.547	.009	.091
Error(ERRORTYP)	1.155	39	2.961E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	25.531	1	25.531	185.073	.000	.826	1.000
SDRTSC	.587	1	.587	4.257	.046	.098	.521
Error	5.380	39	.138				

a Computed using alpha = .05

Spatial Span Forwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	1.224	1	1.224	32.209	.000	.472	1.000
ERRORTYP * SSFSC	3.403E-03	1	3.403E-03	.090	.767	.002	.060
Error(ERRORTYP)	1.368	36	3.801E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	23.818	1	23.818	113.167	.000	.759	1.000
SSFSC	.372	1	.372	1.770	.192	.047	.254
Error	7.577	36	.210				

a Computed using alpha = .05

Spatial Span Backwards

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	1.286	1	1.286	39.026	.000	.507	1.000
ERRORTYP * SSBSC	7.382E-07	1	7.382E-07	.000	.996	.000	.050
Error(ERRORTYP)	1.252	38	3.295E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	20.556	1	20.556	154.656	.000	.803	1.000
SSBSC	1.369	1	1.369	10.298	.003	.213	.878
Error	5.051	38	.133				

a Computed using alpha = .05

Spatial Span Total

Tests of Within-Subjects Effects

Sphericity Assumed Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
ERRORTYP	1.113	1	1.113	32.679	.000	.490	1.000
ERRORTYP * SSTSC	5.585E-03	1	5.585E-03	.164	.688	.005	.068
Error(ERRORTYP)	1.158	34	3.405E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	22.347	1	22.347	105.952	.000	.757	1.000
SSTSC	.704	1	.704	3.338	.076	.089	.427
Error	7.171	34	.211				

a Computed using alpha = .05

APPENDIX C

Key to Raw Data

Visual Interference Pilot Study

wv6_9	visual patterns levels 6-9 with interference
wv10_13	visual patterns levels 10-13 with interference
wvpt	total number of squares, with interference
vpt	total number of squares, without interference
alv6_9	number of arrows correct at levels 6-9
alv10_13	number of arrows correct at levels 10-13
arrcor	total number of arrows correct

Central Executive Pilot Study

weq	number of correct equations, with interference
eq	number of equations correct, without interference
wdot	number of dots correct, with interference
dot	number of dots correct, without interference

EXPERIMENT 2 Raw Data Set

Visual Interference Pilot Study

	Visual Patterns Test				Arrows		
ID#	wv6_9	wv10_13	wvpt	vpt	alv6_9	alv10_13	arrcor
8	98	58	126	122	50	100	80
9	82	40	96	116	33	100	67
10	100	88	151	147	40	67	55
11	52	46	150	124	67	33	67
31	88	80	139	154	67	67	71
32	100	77	141	141	33	33	43
33	60	61	101	116	50	50	60
34	60	58	99	124	0	67	43
35	78	67	119	140	67	100	50
78	97	75	137	146	100	67	83
79	73	59	108	141	67	67	57
80	80	59	112	133	50	50	60
81	88	57	115	136	50	50	60

Central Executive Pilot Study

	Equation		Dots	
ID#	weq	eq	wdot	dot
1	36	38	20	26
3	39	34	31	34
4	33	39	21	28
25	31	35	23	24
26	31	29	12	18
27	36	40	23	37
28	33	31	21	23
49	34	36	26	34
50	34	38	20	28
51	35	35	16	22

Visual Interference Pilot Study

Correlations between the correct number of squares filled and arrows

Total number

		WVPT	ARRCOR
WVPT	Pearson Correlation	1.000	.212
	Sig. (2-tailed)	.	.487
	N	13	13
ARRCOR	Pearson Correlation	.212	1.000
	Sig. (2-tailed)	.487	.
	N	13	13

Levels 6-9

Correlations

		WV6_9	ALV6_9
WV6_9	Pearson Correlation	1.000	.163
	Sig. (2-tailed)	.	.596
	N	13	13
ALV6_9	Pearson Correlation	.163	1.000
	Sig. (2-tailed)	.596	.
	N	13	13

Levels 10-13

Correlations

		WV10_13	ALV10_13
WV10_13	Pearson Correlation	1.000	-.127
	Sig. (2-tailed)	.	.680
	N	13	13
ALV10_13	Pearson Correlation	-.127	1.000
	Sig. (2-tailed)	.680	.
	N	13	13

Repeated measures ANOVA for interference on number of squares correct

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	819.846	1	819.846	6.480	.026	.351	.648
Error(INTERFER)	1518.154	12	126.513				

a Computed using alpha = .05

Central Executive Pilot Study

Repeated measures ANOVA equations

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	8.450	1	8.450	1.407	.266	.135	.186
Error(INTERFER)	54.050	9	6.006				

a Computed using alpha = .05

Repeated measures ANOVA for dots

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	186.050	1	186.050	27.249	.001	.752	.996
Error(INTERFER)	61.450	9	6.828				

a Computed using alpha = .05

APPENDIX D

Information Sheet for Participation in Research Project

University of Tasmania

"Working Memory and Wisconsin Card Sorting Test Performance."

Chief Investigator: Dr Clive Skilbeck
Student Researcher: Jan Martin

You are invited to take part in a PhD project in psychology. The chief investigator is Dr Clive Skilbeck, and the PhD researcher is Jan Martin. The aim of the project is to examine the relationship between working memory and performance on the Wisconsin Card Sorting Test. A better understanding of these tests will potentially benefit neuropsychological patients in the future. Exclusion criteria for the project as detailed in the medical questionnaire.

The study has **one session** of approximately **45 min** and will consist of card sorting tasks and visual and verbal tasks involving patterns and numbers.

In the event of fatigue a break will be permissible between tasks.

All study results will remain confidential. You will not be personally identifiable as you will be allocated an identification number, which will be used on all assessment forms and data analyses.

Assessment data will be kept in locked storage or on secure computer network in the School of Psychology and will be kept separately from personal information to ensure anonymity. Personal information will be destroyed after data collection and analyses. Overall results will be made available on the web at the completion of the study.

You may withdraw from the study at any point without prejudice to your academic standing.

If you wish to be part of this study, have questions, or require further information please contact Jan Martin on 6225 0233 or Dr Clive Skilbeck on 6226 7459.

The project has been approved by the Southern Tasmania Social Sciences Human Research Ethics Committee. If you have any ethical concerns or complaints about the project, you may contact the Chair of the Southern Tasmania Social Sciences Human Research Ethics Committee, A/Professor Margaret Otlowski, on (03) 6226 7569, the Executive Officer, Amanda McAully on (03) 6226 2763 or you may choose to discuss these concerns confidentially with a University Student Counsellor.

Thank you for your time.

Consent to Participate in a Research Project

University in Tasmania

"Working Memory and Wisconsin Card Sorting Test Performance."

I have read and understood the information sheet for this study.

I understand that the study involves the following procedures:

- One session of approximately 45 min duration.
- The session will consist of card sorting tasks and visual and verbal tasks involving patterns and numbers.
- I may take a break between tasks if I become fatigued.

I understand that all research data will be treated as confidential and I will not be personally identifiable.

Any questions that I have asked have been answered to my satisfaction.

I agree that research data gathered for the study may be published provided that I cannot be identified as a participant.

I would like to receive a copy of the results obtained from this study. Yes/No

I agree to take part in this project and understand that I may withdraw at any time without prejudice.

Name of participant: ____

Signature of participant: ______________________Date______________

Statement by Investigator

I have explained this study and the implications of participation in it to this volunteer and I believe that he/she understands it, and that this consent is based on adequate information.

Name of investigator:____

Signature of investigator: ______________________Date______________

Medical Questionnaire – Phone Interview

I am going to ask you a series of medical questions. You don't have to answer each question individually but when I have finished I will ask you if you would have answered 'yes' to one or more of the questions.

Medical History

Are you currently suffering from anxiety, depression, or any psychological condition?................................

Do you have a heart condition or any other serious physical condition?...............

Do you have any difficulties with hearing or vision, which is uncorrected?...........

Have you ever had or are you having treatment for drug or alcohol problems?.............................

Have you ever had or are you subject to any of the following:

Fits or Convulsions................	*Yes*	*No* ....
Epilepsy..............................	*Yes*	*No* ....
Giddiness.............................	*Yes*	*No* ....
Concussion...........................	*Yes*	*No* ....
Severe Head injury.................	*Yes*	*No* ....
Loss of Consciousness...........	Yes	*No* ...

Are you colour-blind?..

Are you currently taking any prescription medication? If so, what medication?...

Key to the Raw Data – Experiment 3

wvf	**Visual feedback, <u>with</u> interference**
vf	**Visual feedback, without interference**
wnvf	**No visual feedback, <u>with</u> interference**
nvf	**No visual feedback, without interference**
cat	categories achieved
err	total errors
pe	perseverative errors
ppe	% perseverative errors
re	random errors

EXPERIMENT 3 Raw Data Set

		Visual Feedback with interference					without interference					No Visual Feedback with interference					without interference				
ID#	group	wvfcat	wvferr	wvfpe	wvfppe	wvfre	vfcat	vferr	vfpe	vfppe	vfre	wnvfcat	wnvfer	wnvfpe	wnvfppe	wnvfre	nvfcat	nvferr	nvfpe	nvfppe	nvfre
1	AS	6	3	1	33	2	7	3	1	33	2	6	2	2	100	0	6	2	1	50	1
2	AS	2	21	12	57	9	3	15	6	40	9	3	12	3	25	9	2	18	6	33	12
3	AS	6	2	0	0	2	6	2	2	100	0	7	1	1	100	0	6	2	2	100	0
4	AS	7	4	3	75	1	8	0	0	0	0	7	1	1	100	0	5	6	1	17	5
5	AS	1	15	5	33	10	5	2	0	0	2	5	8	2	25	6	7	1	0	0	1
6	AS	3	5	1	20	4	7	4	1	25	3	4	7	3	43	4	5	5	1	20	4
7	AS	6	3	0	0	3	6	2	2	100	0	4	6	1	17	5	7	3	1	33	2
8	AS	3	13	3	23	10	8	0	0	0	0	4	7	3	43	4	8	0	0	0	0
9	AS	7	1	1	100	0	8	0	0	0	0	7	1	0	0	1	7	1	1	100	0
10	AS	7	1	0	0	1	7	1	0	0	1	6	6	3	50	3	7	1	0	0	1
11	AS	5	4	1	25	3	7	1	0	0	1	4	9	3	33	6	4	8	4	50	4
12	AS	6	2	0	0	2	6	2	0	0	2	4	4	0	0	4	6	2	0	0	2
13	AS	4	6	1	17	5	6	4	0	0	4	5	8	3	38	5	4	10	3	30	7
14	AS	4	5	2	40	3	7	1	0	0	1	5	3	1	33	2	5	5	1	20	4
15	AS	5	4	0	0	4	4	7	1	14	6	6	3	0	0	3	5	3	0	0	3
16	AS	5	4	1	25	3	5	5	2	40	3	3	6	1	17	5	5	4	3	75	1
17	AS	7	5	3	60	2	8	0	0	0	0	6	3	0	0	3	7	1	1	100	0
18	AS	5	6	4	67	2	7	4	3	75	1	7	2	2	100	0	5	3	2	67	1
19	AS	7	2	1	50	1	7	2	0	0	2	7	1	0	0	1	6	3	2	67	1
20	AS	7	1	0	0	1	8	0	0	0	0	6	7	4	57	3	5	3	2	67	1
21	AS	2	17	3	18	14	5	4	1	25	3	2	13	8	62	5	6	3	2	67	1
22	AS	5	3	1	33	2	4	5	2	40	3	4	7	4	57	3	6	4	0	0	4
23	AS	7	1	1	100	0	7	1	1	100	0	5	4	1	25	3	7	1	0	0	1
24	AS	4	5	1	20	4	7	1	0	0	1	6	4	1	25	3	4	6	1	17	5
25	ST	7	1	0	0	1	7	3	0	0	3	7	3	1	33	2	8	0	0	0	0
26	ST	6	6	2	33	4	7	1	0	0	1	5	3	0	0	3	6	3	1	33	2

EXPERIMENT 3 Raw Data Set

		Visual Feedback with interference					without interference					No Visual Feedback with interference					without interference				
ID#	group	wvfcat	wvferr	wvfpe	wvfppe	wvfre	vfcat	vferr	vfpe	vfppe	vfre	wnvfcat	wnvfer	wnvfpe	wnvfppe	wnvfre	nvfcat	nvferr	nvfpe	nvfppe	nvfre
27	ST	7	1	1	100	0	8	0	0	0	0	8	0	0	0	0	6	2	0	0	2
28	ST	6	3	1	33	2	6	2	0	0	2	4	10	4	40	6	7	5	0	0	5
29	ST	6	8	0	0	8	7	2	1	50	1	7	1	0	0	1	5	4	0	0	4
30	ST	8	0	0	0	0	7	1	0	0	1	8	0	0	0	0	8	0	0	0	0
31	ST	5	5	0	0	5	8	0	0	0	0	7	1	0	0	1	8	0	0	0	0
32	ST	8	0	0	0	0	7	1	0	0	1	8	0	0	0	0	8	0	0	0	0
33	ST	2	15	5	33	10	8	0	0	0	0	5	5	0	0	5	8	0	0	0	0
34	ST	6	4	1	25	3	6	2	1	50	1	7	3	0	0	3	7	1	0	0	1
35	ST	7	1	0	0	1	4	9	4	44	5	7	1	1	100	0	7	2	1	50	1
36	ST	5	4	2	50	2	6	5	0	0	5	4	11	4	36	7	5	5	2	40	3
37	ST	5	3	3	100	0	6	2	1	50	1	3	6	1	17	5	3	7	2	29	5
38	ST	3	10	4	40	6	5	2	1	50	1	1	20	10	50	10	4	6	1	17	5
39	ST	8	0	0	0	0	7	1	0	0	1	7	1	0	0	1	6	4	1	25	3
40	ST	4	5	0	0	5	7	1	0	0	1	7	1	1	100	0	7	3	0	0	3
41	ST	7	1	0	0	1	8	0	0	0	0	4	8	4	50	4	7	1	0	0	1
42	ST	6	5	0	0	5	5	3	1	33	2	3	7	1	14	6	7	4	1	25	3
43	ST	6	2	2	100	0	6	4	0	0	4	5	3	2	67	1	6	3	0	0	3
44	ST	5	5	0	0	5	4	4	0	0	4	7	1	0	0	1	5	3	1	33	2
45	ST	4	7	5	71	2	7	1	0	0	1	3	10	2	20	8	5	3	1	33	2
46	ST	7	1	0	0	1	8	0	0	0	0	6	3	1	33	2	5	3	3	100	0
47	ST	6	2	1	50	1	6	2	1	50	1	4	5	2	40	3	5	9	4	44	5
48	ST	4	5	1	20	4	6	2	0	0	2	5	3	1	33	2	7	1	0	0	1
49	VI	7	4	0	0	4	8	0	0	0	0	8	0	0	0	0	7	1	1	100	0
50	VI	8	0	0	0	0	5	5	0	0	5	6	4	1	25	3	5	5	2	40	3
51	VI	7	1	0	0	1	7	4	0	0	4	7	1	1	100	0	8	0	0	0	0
52	VI	0	22	2	9	20	5	11	2	18	9	0	27	8	30	19	0	29	10	34	19

EXPERIMENT 3 Raw Data Set

		Visual Feedback with interference					without interference					No Visual Feedback with interference					without interference				
ID#	group	wvfcat	wvferr	wvfpe	wvfppe	wvfre	vfcat	vferr	vfpe	vfppe	vfre	wnvfcat	wnvfer	wnvfpe	wnvfppe	wnvfre	nvfcat	nvferr	nvfpe	nvfppe	nvfre
53	VI	5	6	1	17	5	2	11	3	27	8	4	9	3	33	6	4	8	1	13	7
54	VI	3	10	2	20	8	1	14	6	43	8	0	27	9	33	18	2	18	7	39	11
55	VI	7	1	0	0	1	7	1	0	0	1	4	10	2	20	8	7	1	0	0	1
56	VI	3	12	5	42	7	4	7	1	14	6	2	18	5	28	13	7	2	1	50	1
57	VI	7	1	1	100	0	7	1	0	0	1	6	3	1	33	2	8	0	0	0	0
58	VI	4	6	2	33	4	4	8	1	13	7	3	12	5	42	7	5	7	2	29	5
59	VI	7	2	1	50	1	5	6	2	33	4	4	11	6	55	5	7	1	0	0	1
60	VI	7	1	1	100	0	7	1	0	0	1	5	4	1	25	3	6	2	1	50	1
61	VI	6	2	0	0	2	7	2	0	0	2	7	1	1	100	0	8	0	0	0	0
62	VI	7	1	1	100	0	7	1	0	0	1	8	0	0	0	0	5	9	6	67	3
63	VI	7	1	1	100	0	7	1	1	100	0	8	0	0	0	0	6	2	2	100	0
64	VI	8	0	0	0	0	7	1	1	100	0	0	17	8	47	9	8	0	0	0	0
65	VI	6	3	1	33	2	8	0	0	0	0	8	0	0	0	0	7	1	0	0	1
66	VI	6	3	2	67	1	7	2	1	50	1	4	9	2	22	7	5	4	1	25	3
67	VI	7	1	0	0	1	6	2	0	0	2	7	1	1	100	0	8	0	0	0	0
68	VI	8	0	0	0	0	8	0	0	0	0	7	1	0	0	1	6	2	1	50	1
69	VI	7	1	0	0	1	7	1	0	0	1	6	4	2	50	2	6	2	1	50	1
70	VI	8	0	0	0	0	8	0	0	0	0	7	1	0	0	1	7	2	1	50	1
71	VI	8	0	0	0	0	7	1	0	0	1	7	1	0	0	1	8	0	0	0	0
72	VI	7	1	0	0	1	7	1	1	100	0	2	14	4	29	10	8	0	0	0	0
73	VTs	4	8	4	50	4	8	0	0	0	0	5	3	1	33	2	4	8	2	25	6
74	VTs	4	7	2	29	5	6	6	3	50	3	8	0	0	0	0	6	2	1	50	1
75	VTs	0	17	5	29	12	3	13	6	46	7	2	23	9	39	14	2	14	5	36	9
76	VTs	8	0	0	0	0	8	0	0	0	0	5	3	2	67	1	7	1	0	0	1
77	VTs	7	1	0	0	1	6	5	2	40	3	7	1	1	100	0	6	4	0	0	4
78	VTs	4	7	2	29	5	7	1	0	0	1	5	5	2	40	3	8	0	0	0	0

EXPERIMENT 3 Raw Data Set

		Visual Feedback										No Visual Feedback									
		with interference					without interference					with interference					without interference				
ID#	group	wvfcat	wvferr	wvfpe	wvfppe	wvfre	vfcat	vferr	vfpe	vfppe	vfre	wnvfcat	wnvfer	wnvfpe	wnvfppe	wnvfre	nvfcat	nvferr	nvfpe	nvfppe	nvfre
79	VTs	7	2	1	50	1	7	1	0	0	1	6	3	1	33	2	7	1	0	0	1
80	VTs	6	2	0	0	2	7	1	0	0	1	8	0	0	0	0	7	1	0	0	1
81	VTs	4	10	4	40	6	7	1	0	0	1	6	2	1	50	1	7	3	2	67	1
82	VTs	3	8	2	25	6	6	3	1	33	2	3	11	1	9	10	7	3	0	0	3
83	VTs	5	6	2	33	4	3	12	5	42	7	1	25	15	60	10	5	5	3	60	2
84	VTs	8	0	0	0	0	7	1	0	0	1	4	5	2	40	3	7	2	1	50	1
85	VTs	6	5	0	0	5	4	7	2	29	5	4	6	2	33	4	4	6	3	50	3
86	VTs	5	4	2	50	2	8	0	0	0	0	3	9	3	33	6	6	5	1	20	4
87	VTs	3	16	5	31	11	4	8	3	38	5	2	15	4	27	11	4	9	4	44	5
88	VTs	8	0	0	0	0	7	1	0	0	1	8	0	0	0	0	7	2	1	50	1
89	VTs	4	11	2	18	9	4	8	1	13	7	3	14	4	29	10	1	18	7	39	11
90	VTs	3	7	1	14	6	5	5	2	40	3	3	13	5	38	8	5	4	3	75	1
91	VTs	7	1	1	100	0	8	0	0	0	0	6	3	1	33	2	7	1	0	0	1
92	VTs	6	5	1	20	4	5	7	2	29	5	4	15	8	53	7	6	4	1	25	3
93	VTs	6	4	0	0	4	7	1	0	0	1	4	5	1	20	4	6	7	2	29	5
94	VTs	7	1	0	0	1	7	1	1	100	0	3	9	3	33	6	7	1	0	0	1
95	VTs	1	16	4	25	12	3	8	5	63	3	0	25	12	48	13	4	6	2	33	4
96	VTs	8	0	0	0	0	7	2	0	0	2	6	6	1	17	5	7	1	1	100	0

Frequencies

Visual feedback variables

	WVFCAT	WVFERR	WVFPPE	WVFRE	VFCAT	VFERR	VFPPE	VFRE
N	96	96	96	96	96	96	96	96
Mean	5.55	4.63	27.76	3.26	6.26	2.99	20.21	2.11
Std. Error of Mean	.20	.50	3.26	.38	.16	.35	3.04	.24
Std. Deviation	1.94	4.91	31.96	3.68	1.54	3.42	29.75	2.33
Skewness	-.862	1.648	1.111	1.820	-1.097	1.663	1.482	1.325
Std. Error of Skewness	.246	.246	.246	.246	.246	.246	.246	.246
Kurtosis	.222	2.482	.263	4.261	.816	2.408	1.388	.990
Std. Error of Kurtosis	.488	.488	.488	.488	.488	.488	.488	.488

	WVFERR SQRT	WVFER LOG	WVFRE SQRT	WVFRE LOG	VFERR SQRT	VFERR LOG	VFRE SQRT	VFRE LOG
N	96	96	96	96	96	96	96	96
Mean	2.1825	.6018	1.9046	.4869	1.8498	.4682	1.6592	.3862
Std. Error of Mean	9.523E-02	3.741E-02	8.161E-02	3.639E-02	7.732E-02	3.423E-02	6.169E-02	3.099E-02
Std. Deviation	.9331	.3666	.7996	.3566	.7576	.3354	.6044	.3036
Skewness	.849	.041	.866	.124	.995	.322	.808	.280
Std. Error of Skewness	.246	.246	.246	.246	.246	.246	.246	.246
Kurtosis	.211	-.765	.402	-.944	.300	-.741	-.251	-.941
Std. Error of Kurtosis	.488	.488	.488	.488	.488	.488	.488	.488

No visual feedback variables

	WNVFCAT	WNVFERR	WNVFPPE	WNVFRE	NVFCAT	NVFERR	NVFPPE	NVFRE
N	96	96	96	96	96	96	96	96
Mean	5.01	6.32	33.23	4.02	5.94	3.83	29.08	2.50
Std. Error of Mean	.22	.66	3.03	.41	.17	.47	3.11	.31
Std. Deviation	2.11	6.47	29.65	4.05	1.65	4.56	30.52	3.05
Skewness	-.501	1.529	.910	1.426	-1.111	2.854	.840	2.589
Std. Error of Skewness	.246	.246	.246	.246	.246	.246	.246	.246
Kurtosis	-.398	2.099	.317	2.268	1.575	10.901	-.136	9.499
Std. Error of Kurtosis	.488	.488	.488	.488	.488	.488	.488	.488

	WNVFER SQRT	WNVFER LOG	WNVFRE SQRT	WNVFRE LOG	NVFERR SQRT	NVFERR LOG	NVFRE SQRT	NVFRE LOG
N	96	96	96	96	96	96	96	96
Mean	2.4727	.6991	2.0725	.5571	2.0163	.5445	1.7434	.4241
Std. Error of Mean	.1128	4.057E-02	8.738E-02	3.792E-02	8.359E-02	3.417E-02	6.962E-02	3.219E-02
Std. Deviation	1.1052	.3975	.8562	.3715	.8191	.3348	.6821	.3154
Skewness	.707	-.121	.570	-.151	1.344	.118	1.277	.351
Std. Error of Skewness	.246	.246	.246	.246	.246	.246	.246	.246
Kurtosis	-.082	-.811	-.210	-.995	3.060	-.233	2.187	-.470
Std. Error of Kurtosis	.488	.488	.488	.488	.488	.488	.488	.488

Categories Achieved

<u>NB</u> Mauchly's Test of Sphericity was nonsignificant for all analyses

4[group] x 2(feedback) x 2(interference) ANOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	17.940	1	17.940	13.343	.000	.127	.951
FEEDBACK * GROUP	2.112	3	.704	.524	.667	.017	.153
Error(FEEDBACK)	123.698	92	1.345				
INTERFER	64.190	1	64.190	33.564	.000	.267	1.000
INTERFER * GROUP	3.612	3	1.204	.630	.598	.020	.177
Error(INTERFER)	175.948	92	1.912				
FEEDBACK * INTERFER	1.148	1	1.148	.709	.402	.008	.133
FEEDBACK * INTERFER * GROUP	13.654	3	4.551	2.811	.044	.084	.659
Error(FEEDBACK* INTERFER)	148.948	92	1.619				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	12432.878	1	12432.878	1488.326	.000	.942	1.000
GROUP	28.341	3	9.447	1.131	.341	.036	.296
Error	768.531	92	8.354				

a Computed using alpha = .05

Articulatory Suppression Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2.667	1	2.667	2.470	.130	.097	.325
Error(FEEDBACK)	24.833	23	1.080				
INTERFER	20.167	1	20.167	11.500	.003	.333	.901
Error(INTERFER)	40.333	23	1.754				
FEEDBACK * INTERFER	4.167	1	4.167	3.382	.079	.128	.422
Error(FEEDBACK*INTERFER)	28.333	23	1.232				

a Computed using alpha = .05

Without interference condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	6.750	1	6.750	5.697	.026	.199	.628
Error(FEEDBACK)	27.250	23	1.185				

a Computed using alpha = .05

With interference condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	8.333E-02	1	8.333E-02	.074	.788	.003	.058
Error(FEEDBACK)	25.917	23	1.127				

a Computed using alpha = .05

Visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	21.333	1	21.333	16.000	.001	.410	.969
Error(INTERFER)	30.667	23	1.333				

a Computed using alpha = .05

No visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	3.000	1	3.000	1.816	.191	.073	.253
Error(INTERFER)	38.000	23	1.652				

a Computed using alpha = .05

Visual Interference Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	9.375	1	9.375	6.712	.016	.226	.699
Error(FEEDBACK)	32.125	23	1.397				
INTERFER	7.042	1	7.042	3.486	.075	.132	.432
Error(INTERFER)	46.458	23	2.020				
FEEDBACK * INTERFER	9.375	1	9.375	3.775	.064	.141	.461
Error(FEEDBACK* INTERFER)	57.125	23	2.484				

a Computed using alpha = .05

With interference condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	18.750	1	18.750	8.099	.009	.260	.778
Error(FEEDBACK)	53.250	23	2.315				

a Computed using alpha = .05

Without interference

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.000	1	.000	.000	1.000	.000	.050
Error(FEEDBACK)	36.000	23	1.565				

a Computed using alpha = .05

No visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	16.333	1	16.333	5.170	.033	.184	.586
Error(INTERFER)	72.667	23	3.159				

a Computed using alpha = .05

Visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	8.333E-02	1	8.333E-02	.062	.806	.003	.057
Error(INTERFER)	30.917	23	1.344				

a Computed using alpha = .05

Spatial Tapping Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	1.500	1	1.500	.945	.341	.039	.154
Error(FEEDBACK)	36.500	23	1.587				
INTERFER	13.500	1	13.500	6.537	.018	.221	.688
Error(INTERFER)	47.500	23	2.065				
FEEDBACK * INTERFER	2.842E-14	1	2.842E-14	.000	1.000	.000	.050
Error(FEEDBACK*INTERFER)	25.000	23	1.087				

a Computed using alpha = .05

Verbal Trails Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	6.510	1	6.510	4.952	.036	.177	.568
Error(FEEDBACK)	30.240	23	1.315				
INTERFER	27.094	1	27.094	14.959	.001	.394	.959
Error(INTERFER)	41.656	23	1.811				
FEEDBACK * INTERFER	1.260	1	1.260	.753	.394	.032	.132
Error(FEEDBACK*INTERFER)	38.490	23	1.673				

a Computed using alpha = .05

Total number of errors (logarithm transformed)

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

4[group] x 2(feedback) x 2(interference) ANOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.723	1	.723	11.847	.001	.114	.926
FEEDBACK * GROUP	5.332E-02	3	1.777E-02	.291	.832	.009	.104
Error(FEEDBACK)	5.612	92	6.100E-02				
INTERFER	1.994	1	1.994	25.368	.000	.216	.999
INTERFER * GROUP	.132	3	4.403E-02	.560	.643	.018	.162
Error(INTERFER)	7.230	92	7.858E-02				
FEEDBACK * INTERFER	1.066E-02	1	1.066E-02	.156	.694	.002	.068
FEEDBACK * INTERFER * GROUP	.507	3	.169	2.474	.066	.075	.597
Error(FEEDBACK*INTERFER)	6.286	92	6.833E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	128.468	1	128.468	425.174	.000	.822	1.000
GROUP	1.494	3	.498	1.648	.184	.051	.419
Error	27.798	92	.302				

a Computed using alpha = .05

Articulatory Suppression Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.134	1	.134	2.818	.107	.109	.363
Error(FEEDBACK)	1.090	23	4.739E-02				
INTERFER	.895	1	.895	12.266	.002	.348	.918
Error(INTERFER)	1.679	23	7.299E-02				
FEEDBACK * INTERFER	8.176E-02	1	8.176E-02	2.121	.159	.084	.287
Error(FEEDBACK* INTERFER)	.887	23	3.855E-02				

a Computed using alpha = .05

Visual Interference Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.268	1	.268	4.375	.048	.160	.518
Error(FEEDBACK)	1.409	23	6.127E-02				
INTERFER	.193	1	.193	2.774	.109	.108	.358
Error(INTERFER)	1.601	23	6.962E-02				
FEEDBACK * INTERFER	.384	1	.384	3.491	.074	.132	.433
Error(FEEDBACK* INTERFER)	2.527	23	.110				

a Computed using alpha = .05

No visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	.561	1	.561	4.226	.051	.155	.504
Error(INTERFER)	3.051	23	.133				

a Computed using alpha = .05

Visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	1.616E-02	1	1.616E-02	.345	.563	.015	.087
Error(INTERFER)	1.077	23	4.685E-02				

a Computed using alpha = .05

Spatial Tapping Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	7.075E-02	1	7.075E-02	1.059	.314	.044	.167
Error(FEEDBACK)	1.537	23	6.683E-02				
INTERFER	.463	1	.463	4.510	.045	.164	.530
Error(INTERFER)	2.359	23	.103				
FEEDBACK * INTERFER	4.522E-02	1	4.522E-02	.929	.345	.039	.152
Error(FEEDBACK* INTERFER)	1.119	23	4.866E-02				

a Computed using alpha = .05

Verbal Trails Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.304	1	.304	4.433	.046	.162	.523
Error(FEEDBACK)	1.576	23	6.850E-02				
INTERFER	.575	1	.575	8.308	.008	.265	.788
Error(INTERFER)	1.591	23	6.916E-02				
FEEDBACK * INTERFER	7.354E-03	1	7.354E-03	.096	.759	.004	.060
Error(FEEDBACK*INTERFER)	1.754	23	7.624E-02				

a Computed using alpha = .05

Random errors (logarithm transformed)

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

4[group] x 2(feedback) x 2(interference) ANOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.280	1	.280	4.260	.042	.044	.533
FEEDBACK * GROUP	1.181E-02	3	3.937E-03	.060	.981	.002	.060
Error(FEEDBACK)	6.056	92	6.583E-02				
INTERFER	1.311	1	1.311	17.410	.000	.159	.985
INTERFER * GROUP	.136	3	4.529E-02	.602	.616	.019	.171
Error(INTERFER)	6.927	92	7.530E-02				
FEEDBACK * INTERFER	2.486E-02	1	2.486E-02	.501	.481	.005	.108
FEEDBACK * INTERFER * GROUP	.489	3	.163	3.285	.024	.097	.734
Error(FEEDBACK* INTERFER)	4.564	92	4.961E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	82.524	1	82.524	312.720	.000	.773	1.000
GROUP	.938	3	.313	1.184	.320	.037	.309
Error	24.278	92	.264				

a Computed using alpha = .05

Articulatory Suppression Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	3.577E-02	1	3.577E-02	.737	.400	.031	.130
Error(FEEDBACK)	1.117	23	4.856E-02				
INTERFER	.634	1	.634	8.757	.007	.276	.809
Error(INTERFER)	1.665	23	7.240E-02				
FEEDBACK * INTERFER	7.507E-02	1	7.507E-02	2.352	.139	.093	.312
Error(FEEDBACK* INTERFER)	.734	23	3.192E-02				

a Computed using alpha = .05

Visual Interference Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	.105	1	.105	1.341	.259	.055	.199
Error(FEEDBACK)	1.803	23	7.838E-02				
INTERFER	.125	1	.125	1.899	.181	.076	.262
Error(INTERFER)	1.510	23	6.565E-02				
FEEDBACK * INTERFER	.428	1	.428	7.377	.012	.243	.739
Error(FEEDBACK* INTERFER)	1.336	23	5.808E-02				

a Computed using alpha = .05

Without interference condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	5.456E-02	1	5.456E-02	1.207	.283	.050	.184
Error(FEEDBACK)	1.039	23	4.519E-02				

a Computed using alpha = .05

No visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	.508	1	.508	6.711	.016	.226	.699
Error(INTERFER)	1.740	23	7.565E-02				

a Computed using alpha = .05

Visual feedback condition

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
INTERFER	4.546E-02	1	4.546E-02	.946	.341	.039	.154
Error(INTERFER)	1.106	23	4.808E-02				

a Computed using alpha = .05

Spatial Tapping Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	5.667E-02	1	5.667E-02	.773	.388	.033	.135
Error(FEEDBACK)	1.686	23	7.330E-02				
INTERFER	.188	1	.188	1.795	.193	.072	.250
Error(INTERFER)	2.403	23	.104				
FEEDBACK * INTERFER	9.174E-03	1	9.174E-03	.184	.672	.008	.070
Error(FEEDBACK* INTERFER)	1.144	23	4.975E-02				

a Computed using alpha = .05

Verbal Trails Group

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	9.465E-02	1	9.465E-02	1.501	.233	.061	.217
Error(FEEDBACK)	1.450	23	6.306E-02				
INTERFER	.501	1	.501	8.533	.008	.271	.799
Error(INTERFER)	1.349	23	5.867E-02				
FEEDBACK * INTERFER	9.315E-04	1	9.315E-04	.016	.901	.001	.052
Error(FEEDBACK* INTERFER)	1.349	23	5.867E-02				

a Computed using alpha = .05

Percentage perseverative errors

<u>NB</u> Mauchly's Test of Sphericity was nonsignificant for all analyses

4[group] x 2(feedback) x 2(interference) ANOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	4937.836	1	4937.836	6.066	.016	.062	.683
FEEDBACK * GROUP	1254.966	3	418.322	.514	.674	.016	.151
Error(FEEDBACK)	74890.948	92	814.032				
INTERFER	3284.190	1	3284.190	3.920	.051	.041	.500
INTERFER * GROUP	1018.029	3	339.343	.405	.750	.013	.128
Error(INTERFER)	77081.531	92	837.843				
FEEDBACK * INTERFER	278.461	1	278.461	.260	.611	.003	.080
FEEDBACK * INTERFER * GROUP	312.299	3	104.100	.097	.961	.003	.067
Error(FEEDBACK* INTERFER)	98609.990	92	1071.848				

a Computed using alpha = .05

APPENDIX E

Information Sheet for Participation in Research Project

University of Tasmania

"Working Memory and Wisconsin Card Sorting Test Performance."

Chief Investigator: Dr Clive Skilbeck
PhD Researcher: Jan Martin

You are invited to take part in a PhD project in psychology. The chief investigator is Dr Clive Skilbeck, Associate Professor in Clinical Psychology and the PhD researcher is Jan Martin. The aim of the project is to examine the relationship between working memory and performance on a test of planning ability. A better understanding of these tests will potentially benefit neuropsychological patients in the future.

You have been selected to participate as a control subject in the study because no impairment in working memory was identified in your baseline neuropsychological assessment immediately following your head injury.

The study has one session only that will consist of two card-sorting tasks. These tasks will be included in your next two-week follow-up assessment with the Neurotrauma Register and will increase the duration of your appointment by approximately 20 minutes.

In the event of fatigue a break will be permissible between tasks.

Verbal feedback regarding your recovery process can be arranged with the Neurotrauma staff, if requested.

All study results will remain confidential. You will not be personally identifiable as you will be allocated an identification number, which will be used on all assessment forms and data analyses.

Assessment data will be kept in locked storage or on secure computer network in the School of Psychology. No personally identifiable information will be required.

You may withdraw from the study at any point without prejudice to your medical treatment.

If you wish to be part of this study, have questions, or require further information please contact Jan Martin on 0422 501 154 or Dr Clive Skilbeck on 6226 7459.

The project has been approved by the Human Research Ethics Committee (Tasmania) Network. If you have any ethical concerns or complaints about the project, you may contact the Executive Officer of the Human Research Ethics Committee (Tasmania) Network, Amanda McAully on (03) 6226 2763.

Thank you for your time.

Information Sheet for Participation in Research Project

University of Tasmania

"Working Memory and Wisconsin Card Sorting Test Performance."

Chief Investigator: Dr Clive Skilbeck
PhD Researcher: Jan Martin

You are invited to take part in a PhD project in psychology. The chief investigator is Dr Clive Skilbeck, Associate Professor in Clinical Psychology and the PhD researcher is Jan Martin. The aim of the project is to examine the relationship between working memory and performance on a test of planning ability. A better understanding of these tests will potentially benefit neuropsychological patients in the future.

You have been selected to participate in the study because some initial impairment in cognitive functioning was identified in your baseline neuropsychological assessment immediately following your head injury.

The study has one session only that will consist of two card-sorting tasks. These tasks will be included in your next two-week follow-up assessment with the Neurotrauma Register and will increase the duration of your appointment by approximately 20 minutes.

In the event of fatigue a break will be permissible between tasks.

Verbal feedback regarding your recovery process can be arranged with the Neurotrauma staff, if requested.

All study results will remain confidential. You will not be personally identifiable as you will be allocated an identification number, which will be used on all assessment forms and data analyses.

Assessment data will be kept in locked storage or on secure computer network in the School of Psychology. No personally identifiable information will be required.

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Thank you for your time.

University in Tasmania

Consent to Participate in a Research Project

"Working Memory and Wisconsin Card Sorting Test Performance."

I have read and understood the information sheet for this study and acknowledge that I have been selected to participate as a control subject because no impairment in working memory was identified on assessment immediately following my head injury.

I understand that the study involves the following procedures:

- There will be one session only, which will be included in my next two-week follow-up assessment with the Neurotrauma Register.
- The additional tasks will extend the duration of my appointment by approximately 20 minutes.
- The session will consist of two card-sorting tasks.
- I may take a break between tasks if I become fatigued.

I understand that I may request verbal feedback on my recovery process, which will be arranged with the Neurotrauma staff.

I understand that all research data will be treated as confidential and I will not be personally identifiable.

Any questions that I have asked have been answered to my satisfaction.

I agree that research data gathered for the study may be published provided that I cannot be identified as a participant.

I have been offered a copy of the patient information sheet and Consent form.

I agree to take part in this project and understand that I may withdraw at any time without prejudice.

Name of participant: ____

Signature of participant: ____________________Date________________

Statement by Investigator

I have explained this study and the implications of participation in it to this volunteer and I believe that he/she understands it, and that this consent is based on adequate information.

Name of investigator:____

Signature of investigator: ____________________Date________________

University in Tasmania

Consent to Participate in a Research Project

"Working Memory and Wisconsin Card Sorting Test Performance."

I have read and understood the information sheet for this study and acknowledge that I have been selected because I have sustained some initial impairment in cognitive functioning following my head injury.

I understand that the study involves the following procedures:

- There will be one session only, which will be included in my next two-week follow-up assessment with the Neurotrauma Register.
- The additional tasks will extend the duration of my appointment by approximately 20 minutes.
- The session will consist of two card-sorting tasks.
- I may take a break between tasks if I become fatigued.

I understand that I may request verbal feedback on my recovery process, which will be arranged with the Neurotrauma staff.

I understand that all research data will be treated as confidential and I will not be personally identifiable.

Any questions that I have asked have been answered to my satisfaction.

I agree that research data gathered for the study may be published provided that I cannot be identified as a participant.

I have been offered a copy of the patient information sheet and Consent form.

I agree to take part in this project and understand that I may withdraw at any time without prejudice.

Name of participant: ____

Signature of participant: ______________________ Date________________

<u>Statement by Investigator</u>

I have explained this study and the implications of participation in it to this volunteer and I believe that he/she understands it, and that this consent is based on adequate information.

Name of investigator:____

Signature of investigator: ______________________ Date________________

Key to Data – Experiment 4

sex	1=male; 2=female
injury severity	number of days in PTA
injury class	severity classification: 1=mild; 2=moderate
vf	**visual feedback**
nvf	**no visual feedback**
cat	categories achieved
err	total errors
pe	perseverative errors
ppe	percentage of perseverative errors
re	random errors
los	loss of set
fes	failure to establish set
FSIQ	Full Scale IQ
dsfb	Digit Span forward minus backward string
vptpile	Visual Patterns Test percentile
brixpile	Brixton percentile
faspile	FAS percentile
iptot	Information Processing total score
iperror	Information Processing error score
ipspeed	Information Processing speed score
ipadjust	Information Processing adjusted score

EXPERIMENT 4 Raw Data Set

					Injury		Visual Feedback							No Visual Feedback						
ID#	Group	Age	Sex	Edu	Severity	class	vfcat	vferr	vfpe	vfppe	vfre	vflos	vffes	nvfcat	nvferr	nvfpe	nvfppe	nvfre	nvflos	nvffes
1	HC	17	2	11	1	1	8	0	0	0	0	0	0	8	0	0	0	0	0	0
2	HC	33	1	17	0	1	7	1	0	0	1	0	0	7	4	2	50	2	0	1
3	HC	24	1	12	0.083	1	6	4	2	50	2	0	1	8	0	0	0	0	0	0
4	HC	19	2	13	0	1	8	0	0	0	0	0	0	7	3	0	0	3	1	1
5	HC	75	1	15	0.001	1	7	3	2	67	1	0	1	6	3	3	100	0	0	0
6	HC	76	1	14	0.01	1	4	10	3	30	7	0	2	6	3	2	67	1	0	1
7	HC	35	2	10	0.005	1	7	1	0	0	1	0	0	5	6	0	0	6	1	1
8	HC	32	1	16	0.014	1	7	3	2	67	1	1	0	6	2	0	0	2	2	0
9	HC	22	1	13	0	1	7	1	0	0	1	1	0	5	4	2	50	2	0	0
10	HC	35	1	10	0.021	1	8	0	0	0	0	0	0	8	0	0	0	0	0	0
11	HC	21	2	11	1	1	6	4	2	50	2	1	1	4	5	1	20	4	3	0
12	HC	42	1	12	0.042	1	8	0	0	0	0	0	0	7	2	1	50	1	0	0
13	HC	23	2	17	0.021	1	3	8	2	33	6	1	1	8	0	0	0	0	0	0
14	HC	19	1	13	0.021	1	8	0	0	0	0	0	0	7	1	0	0	1	0	0
15	HC	46	1	12	0	1	7	1	0	0	1	1	0	8	0	0	0	0	0	0
16	HC	41	2	10	0.208	1	7	3	1	33	2	0	0	6	2	0	0	2	0	0
21	Ed	54	1	8	0	1	0	19	8	42	11	1	2	0	24	11	46	13	3	3
22	Ed	25	1	13	0.125	2	8	0	0	0	0	0	0	7	2	0	50	1	0	0
23	Ed	19	2	10	0.003	1	4	8	3	38	5	1	1	5	3	2	67	1	0	0
24	Ed	53	1	9	0	1	3	13	5	39	8	0	2	5	5	1	20	4	1	1
25	Ed	23	1	12	3	2	8	0	0	0	0	0	0	2	12	3	25	9	2	2
26	Ed	54	1	12	2	2	6	2	0	0	2	1	0	7	2	0	0	2	0	1
27	Ed	21	1	13	0.063	2	7	1	0	0	1	0	1	4	4	2	50	2	1	0
28	Ed	20	1	11	21	2	6	3	1	33	2	0	1	5	6	2	33	4	1	0
29	Ed	56	2	10	2	2	4	6	0	0	6	0	2	2	21	7	33	14	1	3
30	Ed	42	1	12	0	1	5	8	3	37	5	0	1	3	18	10	56	8	1	4

EXPERIMENT 4 Raw Data Set

ID#	Group	Age	Sex	Edu	Injury Severity	class	Visual Feedback vfcat	vferr	vfpe	vfppe	vfre	vflos	vffes	No Visual Feedback nvfcat	nvferr	nvfpe	nvfppe	nvfre	nvflos	nvffes
31	Ed	19	2	12	0	1	8	0	0	0	0	0	0	7	2	0	0	2	0	0
32	Ed	23	1	12	0.117	2	8	0	0	0	0	0	0	8	0	0	0	0	0	0
33	Ed	18	2	13	0.25	2	8	0	0	0	0	0	0	6	2	1	50	1	1	0
34	Ed	20	1	10	0	1	3	8	2	25	6	0	2	7	1	0	0	1	0	0
35	Ed	28	1	10	0.083	2	7	2	1	50	1	0	0	6	3	1	33	2	1	0
36	Ed	16	2	11	0.167	2	7	2	1	50	1	0	1	5	5	3	60	2	0	0
37	Ed	53	1	15	1	2	6	2	0	0	2	1	0	6	3	0	0	3	0	1
38	Ed	33	1	10	0.333	2	6	2	1	50	1	0	0	7	1	1	100	0	0	0
39	Ed	20	1	10	1	2	8	0	0	0	0	0	0	3	15	4	27	11	1	2
40	Ed	21	1	8	1	2	6	4	0	0	4	1	0	6	3	1	33	2	0	1
41	Ad	24	1	10	7	2	5	7	3	43	4	1	1	4	10	0	0	10	1	2
42	Ad	16	1	10	0.134	2	6	2	1	50	1	0	0	5	5	3	60	2	0	0
43	Ad	25	1	15	1	2	3	12	3	33	9	2	1	6	5	3	60	2	1	0
44	Ad	41	1	11	2	2	5	7	4	57	3	0	1	4	8	4	50	4	0	2
45	Ad	20	1	15	1	2	8	0	0	0	0	0	0	7	1	1	100	0	0	0
46	Ad	21	1	11	0.042	1	7	1	0	0	1	0	0	4	7	3	43	4	0	1
61	Vd	29	1	10	0.042	1	5	5	2	40	3	0	1	0	26	13	50	13	1	5
62	Vd	31	2	10	0.417	2	5	10	1	10	9	0	3	1	21	12	57	9	0	4
63	Vd	21	1	12	2	2	3	10	4	40	6	0	2	2	10	3	30	7	2	3
64	Vd	32	1	7	0	1	1	16	4	25	12	2	3	2	15	9	60	6	0	4
65	Vd	68	1	14	0.007	1	2	14	4	29	10	3	2	2	16	5	31	11	2	3
66	Vd	29	1	10	1	2	5	6	4	67	2	0	1	7	1	0	0	1	0	0
67	Vd	42	1	9	0.042	1	5	5	1	20	4	0	1	4	5	0	0	5	1	0
68	Vd	23	1	12	0.083	2	3	12	5	42	7	1	3	4	13	3	30	10	0	3
69	Vd	16	1	10	2	2	4	5	2	40	3	1	0	6	4	2	50	2	1	0
70	Vd	44	1	13	0	1	7	4	3	75	1	0	1	5	7	3	43	4	1	1

EXPERIMENT 4 Raw Data Set

					Injury		Visual Feedback							No Visual Feedback						
ID#	Group	Age	Sex	Edu	Severity	class	vfcat	vferr	vfpe	vfppe	vfre	vflos	vffes	nvfcat	nvferr	nvfpe	nvfppe	nvfre	nvflos	nvffes
71	Vd	21	1	12	2	2	4	12	3	25	9	0	3	2	20	7	35	13	3	2
72	Vd	32	1	10	4	2	4	16	12	75	4	0	3	5	11	5	45	6	0	2
73	Vd	25	2	10	2	2	8	0	0	0	0	0	0	6	4	2	50	2	0	0
74	Vd	24	1	10	0	1	2	14	9	64	5	0	2	1	13	9	69	4	0	3
75	Vd	35	2	12	0.001	1	8	0	0	0	0	0	0	3	13	5	39	8	1	2
76	Vd	26	1	11	0.003	1	2	13	5	38	8	1	2	6	2	0	0	2	2	0
77	Vd	48	1	15	0.003	1	2	20	6	30	14	1	3	2	16	6	38	10	1	1

EXPERIMENT4 Raw Data Set

ID#	Group	FSIQ	dsfb	vptpile	brixpile	tmtpile	faspile	Information processing iptot	iperror	ipspeed	ipadjust
1	HC	102	2	70	99	92	62	32	88	84	27
2	HC	108	1	95	95	77	55	99	50	77	99
3	HC	91	1	97	75	85	50	50	88	77	50
4	HC	116	0	50	95	85	35	10	88	91	8
5	HC	122	2	92	75	90	85	77	81	93	75
6	HC	122	2	60	75	75	75	n/a	n/a	n/a	n/a
7	HC	113	1	70	75	35	65	94	73	34	96
8	HC	102	1	99	90	55	27	86	50	53	87
9	HC	113	2	50	75	80	30	84	70	77	84
10	HC	108	0	50	75	60	60	88	82	42	90
11	HC	93	2	86	99	70	53	42	70	63	42
12	HC	109	2	98	50	99	53	95	73	87	100
13	HC	112	2	85	90	60	50	63	58	98	58
14	HC	106	1	50	75	30	30	70	14	21	75
15	HC	113	2	87	50	84	50	99	63	99	99
16	HC	99	2	50	75	65	50	98	63	55	99
21	Ed	91	2	37	50	1	1	4	75	18	4
22	Ed	93	0	96	50	1	10	42	70	2	53
23	Ed	100	2	70	75	1	1	30	23	3	37
24	Ed	85	2	53	50	1	1	9	75	66	8
25	Ed	88	1	95	25	30	12	50	70	50	47
26	Ed	115	1	29	75	1	1	63	68	30	63
27	Ed	107	1	70	10	1	70	91	0.1	75	91
28	Ed	82	1	70	99	1	5	14	88	19	14
29	Ed	111	2	73	25	20	60	55	55	79	53
30	Ed	109	2	50	25	1	20	25	63	13	30

EXPERIMENT4 Raw Data Set

ID#	Group	FSIQ	dsfb	vptpile	brixpile	tmtpile	faspile	Information processing			
								iptot	iperror	ipspeed	ipadjust
31	Ed	103	2	85	25	1	60	27	70	77	25
32	Ed	85	2	70	90	1	5	5	58	58	5
33	Ed	103	0	70	75	1	10	86	70	63	86
34	Ed	84	1	50	50	1	1	34	34	53	32
35	Ed	102	2	50	50	1	18	50	58	75	53
36	Ed	102	1	69	90	1	10	19	0.1	2	23
37	Ed	111	1	69	10	1	40	23	68	27	21
38	Ed	105	2	50	75	23	1	86	82	50	87
39	Ed	92	2	69	75	1	13	19	8	53	19
40	Ed	107	1	86	25	1	22	8	88	8	8
41	Ad	116	4	69	75	1	10	32	58	30	32
42	Ad	107	3	50	10	1	20	42	70	50	45
43	Ad	111	3	70	75	18	10	88	88	99.9	86
44	Ad	88	3	50	1	1	1	34	63	58	32
45	Ad	108	3	70	99	1	10	32	70	92	32
46	Ad	n/a	3	50	75	20	1	77	47	75	77
61	Vd	88	2	27	1	1	1	47	8	21	45
62	Vd	n/a	2	7	50	1	1	0.3	70	0.5	0.3
63	Vd	84	2	17	50	1	1	42	58	25	42
64	Vd	75	2	1	90	1	10	12	63	10	14
65	Vd	115	0	18	50	10	7	73	81	32	75
66	Vd	74	2	17	75	1	1	2	23	53	2
67	Vd	75	0	17	75	1	1	18	82	45	18
68	Vd	115	2	1	75	1	1	5	88	19	5
69	Vd	83	0	27	25	1	1	30	34	30	27
70	Vd	102	2	27	10	1	18	4	82	1	5

EXPERIMENT4 Raw Data Set

ID#	Group	FSIQ	dsfb	vptpile	brixpile	tmtpile	faspile	Information processing iptot	iperror	ipspeed	ipadjust
71	Vd	100	1	1	10	40	23	37	14	91	32
72	Vd	93	1	27	50	1	10	50	19	32	53
73	Vd	90	1	18	50	1	10	32	58	4	37
74	Vd	n/a	0	1	25	1	12	5	8	32	4
75	Vd	95	2	18	25	1	1	27	39	53	27
76	Vd	98	-1	27	50	1	10	18	70	63	19
77	Vd	109	2	1	1	1	1	5	63	4	7

One-way ANOVAs

Demographic variables

AGE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	501.037	3	167.012	.760	.521
Within Groups	12089.065	55	219.801		
Total	12590.102	58			

FSIQ

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1956.308	3	652.103	5.371	.003
Within Groups	6313.621	52	121.416		
Total	8269.929	55			

Head-injured controls (HC); Executive dysfunction group (Ed)

		Sum of Squares	df	Mean Square	F	Sig.
FSIQ	Between Groups	770.868	1	770.868	8.058	.008
	Within Groups	3252.688	34	95.667		
	Total	4023.556	35			

Head-injured controls (HC); Auditory dysfunction group (Ad)

		Sum of Squares	df	Mean Square	F	Sig.
FSIQ	Between Groups	16.205	1	16.205	.184	.673
	Within Groups	1672.938	19	88.049		
	Total	1689.143	20			

Head-injured controls (HC); Visual dysfunction group (Vd)

		Sum of Squares	df	Mean Square	F	Sig.
FSIQ	Between Groups	1740.968	1	1740.968	13.196	.001
	Within Groups	3825.871	29	131.927		
	Total	5566.839	30			

Executive dysfunction group (Ed); Auditory dysfunction group (Ad)

		Sum of Squares	df	Mean Square	F	Sig.
FSIQ	Between Groups	210.250	1	210.250	1.944	.177
	Within Groups	2487.750	23	108.163		
	Total	2698.000	24			

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

		Sum of Squares	df	Mean Square	F	Sig.
FSIQ	Between Groups	276.860	1	276.860	1.969	.170
	Within Groups	4640.683	33	140.627		
	Total	4917.543	34			

Auditory dysfunction group (Ad); Visual dysfunction group (Vd)

		Sum of Squares	df	Mean Square	F	Sig.
FSIQ	Between Groups	627.267	1	627.267	3.689	.071
	Within Groups	3060.933	18	170.052		
	Total	3688.200	19			

Cognitive variables

ANOVA-all four groups

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	18.670	3	6.223	10.055	.000
	Within Groups	34.041	55	.619		
	Total	52.712	58			
VPTPILE	Between Groups	35469.970	3	11823.323	44.922	.000
	Within Groups	14475.691	55	263.194		
	Total	49945.661	58			
BRIXPILE	Between Groups	12228.435	3	4076.145	5.808	.002
	Within Groups	38598.548	55	701.792		
	Total	50826.983	58			
TMTPILE	Between Groups	52069.288	3	17356.429	104.543	.000
	Within Groups	9131.221	55	166.022		
	Total	61200.508	58			
FASPILE	Between Groups	19740.425	3	6580.142	25.984	.000
	Within Groups	13928.151	55	253.239		
	Total	33668.576	58			
IPTOT	Between Groups	20240.681	3	6746.894	10.332	.000
	Within Groups	35261.228	54	652.986		
	Total	55501.909	57			
IPERROR	Between Groups	2699.159	3	899.720	1.447	.239
	Within Groups	33587.826	54	621.997		
	Total	36286.985	57			
IPSPEED	Between Groups	15858.281	3	5286.094	7.894	.000
	Within Groups	36162.362	54	669.673		
	Total	52020.643	57			
IPADJUST	Between Groups	19894.596	3	6631.532	9.755	.000
	Within Groups	36708.486	54	679.787		
	Total	56603.082	57			

Head-injured controls (HC): Executive dysfunction group (Ed)

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	1.250E-02	1	1.250E-02	.025	.874
	Within Groups	16.738	34	.492		
	Total	16.750	35			
VPTPILE	Between Groups	682.501	1	682.501	1.919	.175
	Within Groups	12092.388	34	355.658		
	Total	12774.889	35			
BRIXPILE	Between Groups	6384.356	1	6384.356	11.866	.002
	Within Groups	18293.950	34	538.057		
	Total	24678.306	35			
TMTPILE	Between Groups	39753.472	1	39753.472	186.926	.000
	Within Groups	7230.750	34	212.669		
	Total	46984.222	35			
FASPILE	Between Groups	10170.050	1	10170.050	26.762	.000
	Within Groups	12920.700	34	380.021		
	Total	23090.750	35			
IPTOT	Between Groups	10781.867	1	10781.867	14.135	.001
	Within Groups	25171.733	33	762.780		
	Total	35953.600	34			
IPERROR	Between Groups	1082.894	1	1082.894	1.784	.191
	Within Groups	20033.708	33	607.082		
	Total	21116.602	34			
IPSPEED	Between Groups	7216.860	1	7216.860	10.418	.003
	Within Groups	22859.883	33	692.724		
	Total	30076.743	34			
IPADJUST	Between Groups	10291.050	1	10291.050	12.760	.001
	Within Groups	26614.550	33	806.502		
	Total	36905.600	34			

Head-injured controls (HC); Auditory dysfunction group (Ad)

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	13.047	1	13.047	29.752	.000
	Within Groups	8.771	20	.439		
	Total	21.818	21			
VPTPILE	Between Groups	914.820	1	914.820	2.765	.112
	Within Groups	6616.271	20	330.814		
	Total	7531.091	21			
BRIXPILE	Between Groups	2392.758	1	2392.758	4.185	.054
	Within Groups	11435.833	20	571.792		
	Total	13828.591	21			
TMTPILE	Between Groups	18083.523	1	18083.523	58.111	.000
	Within Groups	6223.750	20	311.188		
	Total	24307.273	21			
FASPILE	Between Groups	8146.735	1	8146.735	39.633	.000
	Within Groups	4111.083	20	205.554		
	Total	12257.818	21			
IPTOT	Between Groups	2005.719	1	2005.719	2.759	.113
	Within Groups	13814.567	19	727.082		
	Total	15820.286	20			
IPERROR	Between Groups	8.400	1	8.400	.025	.875
	Within Groups	6281.600	19	330.611		
	Total	6290.000	20			
IPSPEED	Between Groups	28.601	1	28.601	.046	.832
	Within Groups	11779.942	19	619.997		
	Total	11808.543	20			
IPADJUST	Between Groups	2061.733	1	2061.733	2.616	.122
	Within Groups	14972.933	19	788.049		
	Total	17034.667	20			

Head-injured controls (HC); Visual dysfunction group (Vd)

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	.562	1	.562	.713	.405
	Within Groups	24.408	31	.787		
	Total	24.970	32			
VPTPILE	Between Groups	29169.425	1	29169.425	115.369	.000
	Within Groups	7837.908	31	252.836		
	Total	37007.333	32			
BRIXPILE	Between Groups	11509.235	1	11509.235	22.879	.000
	Within Groups	15594.765	31	503.057		
	Total	27104.000	32			
TMTPILE	Between Groups	37611.840	1	37611.840	160.685	.000
	Within Groups	7256.221	31	234.072		
	Total	44868.061	32			
FASPILE	Between Groups	17036.314	1	17036.314	114.415	.000
	Within Groups	4615.868	31	148.899		
	Total	21652.182	32			
IPTOT	Between Groups	18750.555	1	18750.555	31.906	.000
	Within Groups	17630.395	30	587.680		
	Total	36380.950	31			
IPERROR	Between Groups	2252.251	1	2252.251	3.767	.062
	Within Groups	17935.718	30	597.857		
	Total	20187.969	31			
IPSPEED	Between Groups	12586.776	1	12586.776	20.903	.000
	Within Groups	18064.404	30	602.147		
	Total	30651.180	31			
IPADJUST	Between Groups	18626.460	1	18626.460	29.367	.000
	Within Groups	19028.202	30	634.273		
	Total	37654.662	31			

Executive dysfunction group (Ed); Auditory dysfunction group (Ad)

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	14.405	1	14.405	35.888	.000
	Within Groups	9.633	24	.401		
	Total	24.038	25			
VPTPILE	Between Groups	150.832	1	150.832	.545	.467
	Within Groups	6637.783	24	276.574		
	Total	6788.615	25			
BRIXPILE	Between Groups	52.832	1	52.832	.055	.816
	Within Groups	23003.783	24	958.491		
	Total	23056.615	25			
TMTPILE	Between Groups	28.846	1	28.846	.369	.549
	Within Groups	1875.000	24	78.125		
	Total	1903.846	25			
FASPILE	Between Groups	406.371	1	406.371	1.047	.316
	Within Groups	9312.283	24	388.012		
	Total	9718.654	25			
IPTOT	Between Groups	883.205	1	883.205	1.202	.284
	Within Groups	17630.833	24	734.618		
	Total	18514.038	25			
IPERROR	Between Groups	446.887	1	446.887	.685	.416
	Within Groups	15652.108	24	652.171		
	Total	16098.995	25			
IPSPEED	Between Groups	3224.867	1	3224.867	4.277	.050
	Within Groups	18097.958	24	754.082		
	Total	21322.825	25			
IPADJUST	Between Groups	746.371	1	746.371	1.013	.324
	Within Groups	17680.283	24	736.678		
	Total	18426.654	25			

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	.459	1	.459	.636	.431
	Within Groups	25.271	35	.722		
	Total	25.730	36			
VPTPILE	Between Groups	23645.390	1	23645.390	105.299	.000
	Within Groups	7859.421	35	224.555		
	Total	31504.811	36			
BRIXPILE	Between Groups	1026.204	1	1026.204	1.322	.258
	Within Groups	27162.715	35	776.078		
	Total	28188.919	36			
TMTPILE	Between Groups	4.205	1	4.205	.051	.823
	Within Groups	2907.471	35	83.071		
	Total	2911.676	36			
FASPILE	Between Groups	1244.662	1	1244.662	4.437	.042
	Within Groups	9817.068	35	280.488		
	Total	11061.730	36			
IPTOT	Between Groups	1562.826	1	1562.826	2.550	.119
	Within Groups	21446.661	35	612.762		
	Total	23009.488	36			
IPERROR	Between Groups	285.274	1	285.274	.366	.549
	Within Groups	27306.226	35	780.178		
	Total	27591.500	36			
IPSPEED	Between Groups	1057.282	1	1057.282	1.518	.226
	Within Groups	24382.421	35	696.641		
	Total	25439.703	36			
IPADJUST	Between Groups	1723.978	1	1723.978	2.776	.105
	Within Groups	21735.552	35	621.016		
	Total	23459.531	36			

Auditory dysfunction group (Ad); Visual dysfunction group (Vd)

		Sum of Squares	df	Mean Square	F	Sig.
DSFB	Between Groups	17.566	1	17.566	21.318	.000
	Within Groups	17.304	21	.824		
	Total	34.870	22			
VPTPILE	Between Groups	8984.348	1	8984.348	79.164	.000
	Within Groups	2383.304	21	113.491		
	Total	11367.652	22			
BRIXPILE	Between Groups	863.141	1	863.141	.893	.355
	Within Groups	20304.598	21	966.886		
	Total	21167.739	22			
TMTPILE	Between Groups	44.747	1	44.747	.494	.490
	Within Groups	1900.471	21	90.499		
	Total	1945.217	22			
FASPILE	Between Groups	22.549	1	22.549	.470	.500
	Within Groups	1007.451	21	47.974		
	Total	1030.000	22			
IPTOT	Between Groups	3202.974	1	3202.974	6.667	.017
	Within Groups	10089.495	21	480.452		
	Total	13292.469	22			
IPERROR	Between Groups	1053.361	1	1053.361	1.632	.215
	Within Groups	13554.118	21	645.434		
	Total	14607.478	22			
IPSPEED	Between Groups	6123.774	1	6123.774	9.667	.005
	Within Groups	13302.479	21	633.451		
	Total	19426.253	22			
IPADJUST	Between Groups	3094.081	1	3094.081	6.437	.019
	Within Groups	10093.936	21	480.664		
	Total	13188.017	22			

Chi-squared analyses

Group numbers

Four Groups

	Observed N	Expected N	Residual
HC	16	14.8	1.3
Ed	20	14.8	5.3
Ad	6	14.8	-8.8
Vd	17	14.8	2.3
Total	59		

	group
Chi-Square	7.508
df	3
Asymp. Sig.	.057

a 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 14.8.

Three Groups

	Observed N	Expected N	Residual
HC	16	17.7	-1.7
Ed	20	17.7	2.3
Vd	17	17.7	-.7
Total	53		

Test Statistics

	group
Chi-Square	.491
df	2
Asymp. Sig.	.782

a 0 cells (.0%) have expected frequencies less than 5. The minimum expected cell frequency is 17.7.

Injury severity

			group		Total
			Ed	Vd	
class	mild	Count	6	9	15
		Expected Count	8.1	6.9	15.0
	moderate	Count	14	8	22
		Expected Count	11.9	10.1	22.0
Total		Count	20	17	37
		Expected Count	20.0	17.0	37.0

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)
Pearson Chi-Square	2.006	1	.157	
Continuity Correction	1.167	1	.280	
Likelihood Ratio	2.018	1	.155	
Fisher's Exact Test				.193
Linear-by-Linear Association	1.952	1	.162	
N of Valid Cases	37			

a Computed only for a 2x2 table
b 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.89.

Frequencies

	VF CAT	NVF CAT	VF ERR	NVF ERR	VF RE	NVF RE	VF PPE	NVF PPE	VF LOS	NVF LOS	VF FES	NVF FES
N	59	59	59	59	59	59	59	59	59	59	59	59
Mean	5.59	5,00	5.25	6,78	3,31	4,08	25.10	33,08	.37	.63	.88	1.02
Std. Error of Mean	.28	,28	.71	,88	,46	,52	3.17	3,66	8.34E-02	.11	.13	.18
Std. Deviation	2.15	2,17	5.47	6,75	3,56	4,01	24.31	28,10	.64	.85	1.02	1.35
Skewness	-.644	-.584	.995	1.226	1.149	1.055	.379	.392	1.923	1.337	.853	1.199
Std. Error of Skewness	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311
Kurtosis	-.553	-.542	.034	.575	.527	-.032	-1.115	-.374	4.195	1.195	-.463	.467
Std. Error of Kurtosis	.613	.613	.613	.613	.613	.613	.613	.613	.613	.613	.613	.613

Frequencies for transformed variables: total errors and random errors

	VFERR SQRT	VFERR LOG	NVFERR SQRT	NVFER LOG	VFRE SQRT	VFRE LOG	NVFRE SQRT	NVFRE LOG
N	59	59	59	59	59	59	59	59
Mean	2.2613	.6053	2.5499	.7263	1.9117	.4864	2.0926	.5709
Std. Error of Mean	.1402	5.683E-02	.1484	5.177E-02	.1059	4.791E-02	.1103	4.633E-02
Std. Deviation	1.0773	.4365	1.1400	.3977	.8136	.3680	.8473	.3559
Skewness	.447	-.106	.647	-.122	.625	.114	.579	-.033
Std. Error of Skewness	.311	.311	.311	.311	.311	.311	.311	.311
Kurtosis	-.975	-1.311	-.536	-.705	-.708	-1.223	-.736	-.912
Std. Error of Kurtosis	.613	.613	.613	.613	.613	.613	.613	.613

Frequencies for transformed variables: loss of set and failure to maintain set

	VFLOS SQRT	VFLOS LOG	NVFLOS SQRT	NVFLOS LOG	VFFES SQRT	VFFES LOG	NVFFES SQRT	NVFFES LOG
N	59	59	59	59	59	59	59	59
Mean	1.1471	.1029	1.2393	.1629	1.3257	.2156	1.3532	.2227
Std. Error of Mean	3.138E-02	2.130E-02	3.969E-02	2.588E-02	4.622E-02	2.926E-02	5.660E-02	3.380E-02
Std. Deviation	.2410	.1636	.3049	.1988	.3550	.2248	.4348	.2597
Skewness	1.500	1.227	.985	.714	.593	.371	.874	.613
Std. Error of Skewness	.311	.311	.311	.311	.311	.311	.311	.311
Kurtosis	1.706	.282	-.008	-.832	-.992	-1.384	-.516	-1.143
Std. Error of Kurtosis	.613	.613	.613	.613	.613	.613	.613	.613

Categories Achieved

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

3[group: HC, Ed, Vd] x 2(feedback: Visual, no visual) ANCOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2.011E-05	1	2.011E-05	.000	.998	.000	.050
FEEDBACK * FSIQ	7.008E-02	1	7.008E-02	.028	.869	.001	.053
FEEDBACK * GROUP	2.385	2	1.193	.471	.627	.020	.123
Error(FEEDBACK)	118.947	47	2.531				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	45.180	1	45.180	9.038	.004	.161	.838
FSIQ	.880	1	.880	.176	.677	.004	.070
GROUP	97.759	2	48.880	9.779	.000	.294	.977
Error	234.937	47	4.999				

a Computed using alpha = .05

Head-injured controls (HC); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	43.080	1	43.080	11.330	.002	.288	.901
FSIQ	3.880	1	3.880	1.021	.321	.035	.164
GROUP	99.546	1	99.546	26.181	.000	.483	.999
Error	106.461	28	3.802				

a Computed using alpha = .05

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	30.055	1	30.055	4.661	.038	.127	.553
FSIQ	.609	1	.609	.094	.761	.003	.060
GROUP	39.086	1	39.086	6.062	.019	.159	.666
Error	206.333	32	6.448				

a Computed using alpha = .05

Head-injured controls (HC); Executive dysfunction group (Ed)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	2629.803	1	2629.803	579.289	.000	.945	1.000
GROUP	26.136	1	26.136	5.757	.022	.145	.645
Error	154.350	34	4.540				

a Computed using alpha = .05

Total errors (logarithm transformed)

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

3[group: HC, Ed, Vd] x 2(feedback: Visual, no visual) ANCOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2.580E-02	1	2.580E-02	.248	.621	.005	.078
FEEDBACK * FSIQ	4.780E-02	1	4.780E-02	.459	.501	.010	.102
FEEDBACK * GROUP	.225	2	.112	1.078	.349	.044	.228
Error(FEEDBACK)	4.896	47	.104				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	3.535E-02	1	3.535E-02	.206	.652	.004	.073
FSIQ	.265	1	.265	1.541	.221	.032	.229
GROUP	4.339	2	2.169	12.631	.000	.350	.995
Error	8.072	47	.172				

a Computed using alpha = .05

Head-injured controls (HC); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	5.060E-04	1	5.060E-04	.004	.952	.000	.050
FSIQ	.365	1	.365	2.681	.113	.087	.353
GROUP	4.221	1	4.221	31.036	.000	.526	1.000
Error	3.808	28	.136				

a Computed using alpha = .05

Head-injured controls (HC); Executive dysfunction group (Ed)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	5.835E-02	1	5.835E-02	.323	.574	.010	.086
FSIQ	2.380E-02	1	2.380E-02	.132	.719	.004	.064
GROUP	.729	1	.729	4.034	.053	.109	.496
Error	5.962	33	.181				

a Computed using alpha = .05

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	8.673E-02	1	8.673E-02	.441	.511	.014	.099
FSIQ	.229	1	.229	1.167	.288	.035	.182
GROUP	1.950	1	1.950	9.925	.004	.237	.863
Error	6.287	32	.196				

a Computed using alpha = .05

Random errors (logarithm transformed)

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

3[group: HC, Ed, Vd] x 2(feedback: Visual, no visual) ANCOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2.238E-03	1	2.238E-03	.028	.868	.001	.053
FEEDBACK * FSIQ	8.709E-07	1	8.709E-07	.000	.997	.000	.050
FEEDBACK * GROUP	8.206E-02	2	4.103E-02	.515	.601	.021	.130
Error(FEEDBACK)	3.747	47	7.971E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1.887E-02	1	1.887E-02	.140	.710	.003	.066
FSIQ	.182	1	.182	1.356	.250	.028	.207
GROUP	3.040	2	1.520	11.303	.000	.325	.989
Error	6.321	47	.134				

a Computed using alpha = .05

Head-injured controls (HC); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1.247E-03	1	1.247E-03	.012	.915	.000	.051
FSIQ	.249	1	.249	2.317	.139	.076	.312
GROUP	2.977	1	2.977	27.736	.000	.498	.999
Error	3.006	28	.107				

a Computed using alpha = .05

Head-injured controls (HC); Executive dysfunction group (Ed)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	7.685E-02	1	7.685E-02	.573	.455	.017	.114
FSIQ	1.455E-03	1	1.455E-03	.011	.918	.000	.051
GROUP	.544	1	.544	4.056	.052	.109	.498
Error	4.428	33	.134				

a Computed using alpha = .05

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	2.376E-02	1	2.376E-02	.149	.702	.005	.066
FSIQ	.226	1	.226	1.417	.243	.042	.211
GROUP	1.280	1	1.280	8.036	.008	.201	.785
Error	5.097	32	.159				

a Computed using alpha = .05

Percentage perseverative errors

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

3[group: HC, Ed, Vd] x 2(feedback: Visual, no visual) ANCOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	1938.784	1	1938.784	4.532	.039	.088	.550
FEEDBACK * FSIQ	2180.732	1	2180.732	5.097	.029	.098	.599
FEEDBACK * GROUP	2321.614	2	1160.807	2.713	.077	.104	.511
Error(FEEDBACK)	20108.079	47	427.831				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	128.206	1	128.206	.160	.691	.003	.068
FSIQ	323.900	1	323.900	.404	.528	.009	.096
GROUP	3309.384	2	1654.692	2.066	.138	.081	.404
Error	37639.061	47	800.831				

a Computed using alpha = .05

Repeated measures ANOVA for the Executive dysfunction group

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2544.025	1	2544.025	8.818	.008	.317	.804
Error(FEEDBACK)	5481.475	19	288.499				

a Computed using alpha = .05

Repeated measures ANOVA for the Visual dysfunction group

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	2.941E-02	1	2.941E-02	.000	.994	.000	.050
Error(FEEDBACK)	8244.471	16	515.279				

a Computed using alpha = .05

One-way ANOVA for Executive dysfunction and Visual dysfunction groups

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
VFPPE	Between Groups	3067.484	1	3067.484	6.168	.018
	Within Groups	17407.435	35	497.355		
	Total	20474.919	36			
NVFPPE	Between Groups	47.008	1	47.008	.080	.779
	Within Groups	20574.668	35	587.848		
	Total	20621.676	36			

Loss of set (logarithm transformed)

<u>NB</u> Mauchly's Test of Sphericity was nonsignificant for all analyses

3[group: HC, Ed, Vd] x 2(feedback: Visual, no visual) ANCOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	8.833E-02	1	8.833E-02	2.963	.092	.059	.392
FEEDBACK * FSIQ	6.777E-02	1	6.777E-02	2.273	.138	.046	.315
FEEDBACK * GROUP	7.722E-03	2	3.861E-03	.130	.879	.005	.069
Error(FEEDBACK)	1.401	47	2.981E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	4.233E-04	1	4.233E-04	.012	.914	.000	.051
FSIQ	1.795E-02	1	1.795E-02	.503	.482	.011	.107
GROUP	.198	2	9.900E-02	2.774	.073	.106	.521
Error	1.677	47	3.569E-02				

a Computed using alpha = .05

Head-injured controls (HC); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1.440E-03	1	1.440E-03	.033	.857	.001	.054
FSIQ	2.899E-02	1	2.899E-02	.663	.422	.023	.123
GROUP	.190	1	.190	4.352	.046	.135	.522
Error	1.224	28	4.372E-02				

a Computed using alpha = .05

Head-injured controls (HC); Executive dysfunction group (Ed)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	4.793E-02	1	4.793E-02	1.514	.227	.044	.223
FSIQ	1.752E-02	1	1.752E-02	.553	.462	.016	.112
GROUP	1.425E-03	1	1.425E-03	.045	.833	.001	.055
Error	1.044	33	3.165E-02				

a Computed using alpha = .05

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	8.366E-03	1	8.366E-03	.265	.610	.008	.079
FSIQ	6.622E-02	1	6.622E-02	2.100	.157	.062	.290
GROUP	.144	1	.144	4.577	.040	.125	.546
Error	1.009	32	3.154E-02				

a Computed using alpha = .05

Failure to establish set (logarithm transformed)

NB Mauchly's Test of Sphericity was nonsignificant for all analyses

3[group: HC, Ed, Vd] x 2(feedback: Visual, no visual) ANCOVA

Tests of Within-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
FEEDBACK	5.536E-02	1	5.536E-02	1.690	.200	.035	.247
FEEDBACK * FSIQ	5.437E-02	1	5.437E-02	1.660	.204	.034	.243
FEEDBACK * GROUP	4.117E-02	2	2.058E-02	.629	.538	.026	.149
Error(FEEDBACK)	1.539	47	3.275E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	5.232	1	5.232	82.486	.000	.623	1.000
GROUP	1.593	2	.796	12.556	.000	.334	.995
Error	3.172	50	6.343E-02				

a Computed using alpha = .05

Head-injured controls (HC); Visual dysfunction (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	7.239E-02	1	7.239E-02	1.330	.259	.045	.200
FSIQ	.220	1	.220	4.038	.054	.126	.492
GROUP	1.346	1	1.346	24.722	.000	.469	.998
Error	1.524	28	5.444E-02				

a Computed using alpha = .05

Head-injured controls (HC); Executive dysfunction group (Ed)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	5.066E-05	1	5.066E-05	.001	.974	.000	.050
FSIQ	1.327E-02	1	1.327E-02	.278	.602	.008	.081
GROUP	.174	1	.174	3.643	.065	.099	.457
Error	1.576	33	4.775E-02				

a Computed using alpha = .05

Executive dysfunction group (Ed); Visual dysfunction group (Vd)

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	8.049E-04	1	8.049E-04	.010	.920	.000	.051
FSIQ	9.362E-02	1	9.362E-02	1.189	.284	.036	.185
GROUP	.625	1	.625	7.940	.008	.199	.780
Error	2.520	32	7.874E-02				

a Computed using alpha = .05

Auditory dysfunction group analyses

Categories achieved

Tests of Between-Subjects Effects with Head-injured controls

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	11.811	1	11.811	5.011	.038	.218	.563
FSIQ	4.577E-02	1	4.577E-02	.019	.891	.001	.052
GROUP	14.687	1	14.687	6.231	.022	.257	.656
Error	42.429	18	2.357				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Executive dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	6.211	1	6.211	.993	.330	.043	.159
FSIQ	1.444	1	1.444	.231	.636	.010	.075
GROUP	.657	1	.657	.105	.749	.005	.061
Error	137.631	22	6.256				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Visual dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	27.819	1	27.819	5.128	.037	.232	.570
FSIQ	2.843	1	2.843	.524	.479	.030	.105
GROUP	16.176	1	16.176	2.982	.102	.149	.371
Error	92.223	17	5.425				

a Computed using alpha = .05

Total errors (logarithm transformed)

Tests of Between-Subjects Effects with Head-injured controls

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	3.428E-02	1	3.428E-02	.221	.644	.012	.073
FSIQ	1.424E-02	1	1.424E-02	.092	.765	.005	.060
GROUP	.793	1	.793	5.118	.036	.221	.572
Error	2.789	18	.155				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Executive dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	.207	1	.207	.883	.357	.039	.147
FSIQ	8.044E-06	1	8.044E-06	.000	.995	.000	.050
GROUP	9.295E-02	1	9.295E-02	.397	.535	.018	.093
Error	5.146	22	.234				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Visual dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1.717E-02	1	1.717E-02	.095	.761	.006	.060
FSIQ	.269	1	.269	1.492	.239	.081	.211
GROUP	.531	1	.531	2.946	.104	.148	.367
Error	3.064	17	.180				

a Computed using alpha = .05

Random errors (logarithm transformed)

Tests of Between-Subjects Effects with Head-injured controls

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	3.278E-02	1	3.278E-02	.277	.605	.015	.079
FSIQ	2.040E-03	1	2.040E-03	.017	.897	.001	.052
GROUP	.367	1	.367	3.105	.095	.147	.385
Error	2.128	18	.118				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Executive dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	8.147E-02	1	8.147E-02	.427	.520	.019	.096
FSIQ	4.557E-03	1	4.557E-03	.024	.879	.001	.053
GROUP	3.508E-03	1	3.508E-03	.018	.893	.001	.052
Error	4.194	22	.191				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Visual dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	5.429E-03	1	5.429E-03	.034	.855	.002	.054
FSIQ	.335	1	.335	2.121	.164	.111	.280
GROUP	.638	1	.638	4.038	.061	.192	.474
Error	2.687	17	.158				

a Computed using alpha = .05

Percentage perseverative errors

Tests of Between-Subjects Effects with Executive dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	966.999	1	966.999	1.163	.293	.050	.178
FSIQ	48.701	1	48.701	.059	.811	.003	.056
GROUP	2674.808	1	2674.808	3.217	.087	.128	.404
Error	18290.574	22	831.390				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Visual dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1412.604	1	1412.604	3.448	.081	.169	.418
FSIQ	47.152	1	47.152	.115	.739	.007	.062
GROUP	753.394	1	753.394	1.839	.193	.098	.249
Error	6965.315	17	409.724				

a Computed using alpha = .05

Loss of set (logarithm transformed)

Tests of Between-Subjects Effects with Head-injured controls

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	4.950E-03	1	4.950E-03	.098	.758	.005	.060
FSIQ	4.208E-05	1	4.208E-05	.001	.977	.000	.050
GROUP	1.102E-02	1	1.102E-02	.217	.647	.012	.073
Error	.913	18	5.074E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Executive dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1.948E-03	1	1.948E-03	.060	.809	.003	.056
FSIQ	1.823E-02	1	1.823E-02	.559	.463	.025	.110
GROUP	3.314E-06	1	3.314E-06	.000	.992	.000	.050
Error	.717	22	3.261E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Visual dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	9.662E-02	1	9.662E-02	2.263	.151	.117	.295
FSIQ	.201	1	.201	4.712	.044	.217	.535
GROUP	.122	1	.122	2.867	.109	.144	.359
Error	.726	17	4.269E-02				

a Computed using alpha = .05

Failure to establish set (logarithm transformed)

Tests of Between-Subjects Effects with Head-injured controls

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	5.640E-04	1	5.640E-04	.015	.902	.001	.052
FSIQ	9.686E-03	1	9.686E-03	.266	.612	.015	.078
GROUP	7.407E-02	1	7.407E-02	2.033	.171	.101	.271
Error	.656	18	3.644E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Executive dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	4.395E-02	1	4.395E-02	.633	.435	.028	.119
FSIQ	6.859E-03	1	6.859E-03	.099	.756	.004	.060
GROUP	4.005E-04	1	4.005E-04	.006	.940	.000	.051
Error	1.528	22	6.946E-02				

a Computed using alpha = .05

Tests of Between-Subjects Effects with Visual dysfunction group

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Observed Power
Intercept	1.276E-02	1	1.276E-02	.137	.716	.008	.064
FSIQ	.109	1	.109	1.176	.293	.065	.176
GROUP	.342	1	.342	3.677	.072	.178	.440
Error	1.581	17	9.298E-02				

a Computed using alpha = .05